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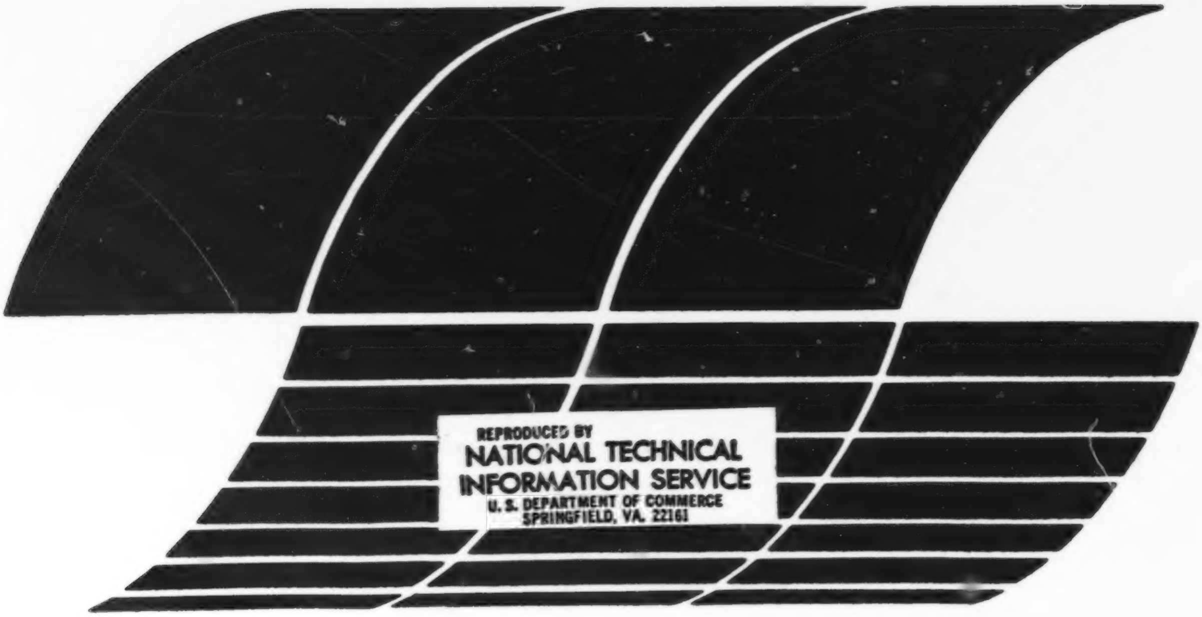

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16. ABSTRACT The report describes preliminary attempts to formulate viable models for interpreting environmental assessment data. The models are evaluated using data from the four most comprehensive environmental assessments. A format for entering environmental assessment results on FORTRAN computer sheets is presented and more complete data entry sheets, being developed by IERL-RTP, are discussed. Various previously proposed models (Source Severity; Source Assessment Models SAM/I, SAM/IA, and SAM/IB) are investigated using the data from the four previously mentioned studies. Correlations between biotests and chemical results, and between biotests, were calculated using the data from these four studies; a summary of possible correlations is presented. In the study of correlations, the data are examined from each study individually and from the entire data set taken as a whole. Generally, results do not reveal a strong degree of association between the chemical analyses and the biological tests. When all factors relevant to an intelligent decision on the acceptability of a waste stream are considered, there appears to be no mathematical model that will encompass all of them. The models are useful but must still be utilized with considerable care.

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ABSTRACT

Nineteen environmental assessment projects were performed on a variety of industrial sources prior to the spring of 1978 and the results were compiled in Compilation of Level 1 Environmental Assessment Data, EPA-600/2-78-211. It became apparent during compilation of the data that methods were needed to organize, summarize, and interpret the bulk of data produced by environmental assessments. Preliminary attempts to formulate viable models for interpreting environmental assessment data are presented in this document. These models are evaluated using data from the four most comprehensive environmental assessments: the three pilot studies (the Exxon fluidized-bed combustor miniplant, the EPA-ATMI study of textile effluents, and the study of a Chapman low-Btu coal gasifier) and a study to evaluate the Source Assessment Sampling System (SASS) train at 10 industrial sites. A format for entering results from environmental assessments on Fortran computer sheets is presented and more complete data entry sheets, being developed by the IERL Special Studies staff, are discussed. Various previously proposed models (Source Severity; Source Assessment Models SAM/I, SAM/IA, and SAM/IB) are investigated using the data from the four previously mentioned studies. Linear (Pearson) and rank (Spearman) correlations between biotests and chemical results, and among biotests, were calculated using the data from these four studies; a summary of possible rank correlations is presented. In the study of correlations, the data are examined from each study individually and from the entire data set taken as a whole. These results must be viewed as preliminary owing to the limited number of data pairs available for calculating many of the correlations. However, it is hoped that the results of the correlation analysis will direct future research in cause-effect relationships and guide future studies. As more complete data become available, the procedures described in this document can be applied to interpret data and develop models.

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SECTION 1

INTRODUCTION

The Industrial Environmental Research Laboratory (IERL) of the Environmental Protection Agency (EPA) has developed a phased methodology for assessing the relative hazard of an industrial effluent and, where necessary, developing and evaluating the best available control technology. The IERL methodology employs both chemical and biological tests in the Level 1 screening phase of this program. Manuals published on Level 1 methods are available from IERL.[1] [2] Level 2 will consist of more specific chemical and/or biological tests to identify and quantify specific hazardous components of a sample. Level 3 will consist of two types of studies: long-term studies to determine changes of an effluent's composition over time and studies to evaluate the effects of applying control technologies.

To date, 19 IERL environmental assessment (EA) programs have been performed for the Level 1 or screening phase. Several Level 2 efforts are or soon will be underway. No Level 3 studies have been initiated at this time.

The EA studies have produced many individual sets of information, and a need has been recognized to consolidate these sets of data into an easily comprehended model. To achieve this end, a project was undertaken to compile all available data on environmental assessments performed prior to the spring of 1978. The culmination of that effort was the Compilation of Level 1 Environmental Assessment Data,[3] published in October 1978. The resulting document contains a brief description of each EA study, a schematic representation or process flow diagram where available, and a brief summary of the results. The data from all EAs were made uniform and consistent for units of measure. Transformation of some results, such as simple ratios or summations, were performed where appropriate. All such transformations and units of measure changes are documented in this data interpretation task in Table 5, page 17.

The purposes of the project were:

1. To identify potential end uses of the EA data, such as prioritization listings, criteria for transitions from one phase or level to the next, decision criteria for applying control technologies, and/or usefulness to EPA's regulatory branches;
2. To develop an appropriate data model for each level;
3. To test this model using data from the three EA pilot studies;
4. To develop standardized reporting formats.

The data used in this task were drawn primarily from the compilation document and are referred to by study number as listed in that document. Other sources of information included unpublished (draft) documents and raw data obtained from the biologists and chemists who performed the testing. The data used in this task were limited to samples for which Level 1 or equivalent methods were employed; additional chemical and physical testing results were not considered. The data were also limited to samples for which both bioassay and chemical results were available, although the results for any given sample may not have included the entire complement of Level 1 chemical tests with biological assays as specified in the Level 1 manual.

There were only four Level 1 environmental assessment studies for which both chemical tests and bioassay results were available; the remaining studies utilized only chemical tests. The chemical testing protocol had preceded the bioassay protocol. These four studies were:

Study number	Industrial source
06	Coal gasifier
10	Fluidized-bed combustor
15	10 different industrial source types
19	23 different textile plants' effluents

Studies 06, 10, and 19 were the IERL pilot studies in which the Level 1 methodology was tested, evaluated, and improved. Study 15 was performed to evaluate the SASS train, a Level 1 sampling apparatus for gaseous and particulate effluents, and involved several kinds of industrial emissions. These studies are described in more detail in Section 2.

Several facts about the data set should be emphasized. With the previously mentioned qualifiers, it contains all available Level 1 data for biological and chemical testing. These data are from the first effort to test the phased approach methodology and this study is the first attempt to bring together and interpret all results of such a program. The data set is small in the statistical sense, but the trends noted in this interpretation effort should be helpful in guiding the direction of future research efforts and studies.

The remainder of the document is divided into four sections. Section 2 describes the sources and the individual sampling points, as well as the format for coding this information for computer use. Section 3 details the methods of quantifying the biological and chemical testing results. Section 4 describes the analysis of the data and the results of this analysis; the various models that have been applied to data in the phased environmental assessment program are discussed. Recommendations based on this study are found in Section 5. Various appendixes are supplied at the end of the document for reference and as detailed background information; these include the original data set and transformations in the SAM/IA model.

SECTION 2

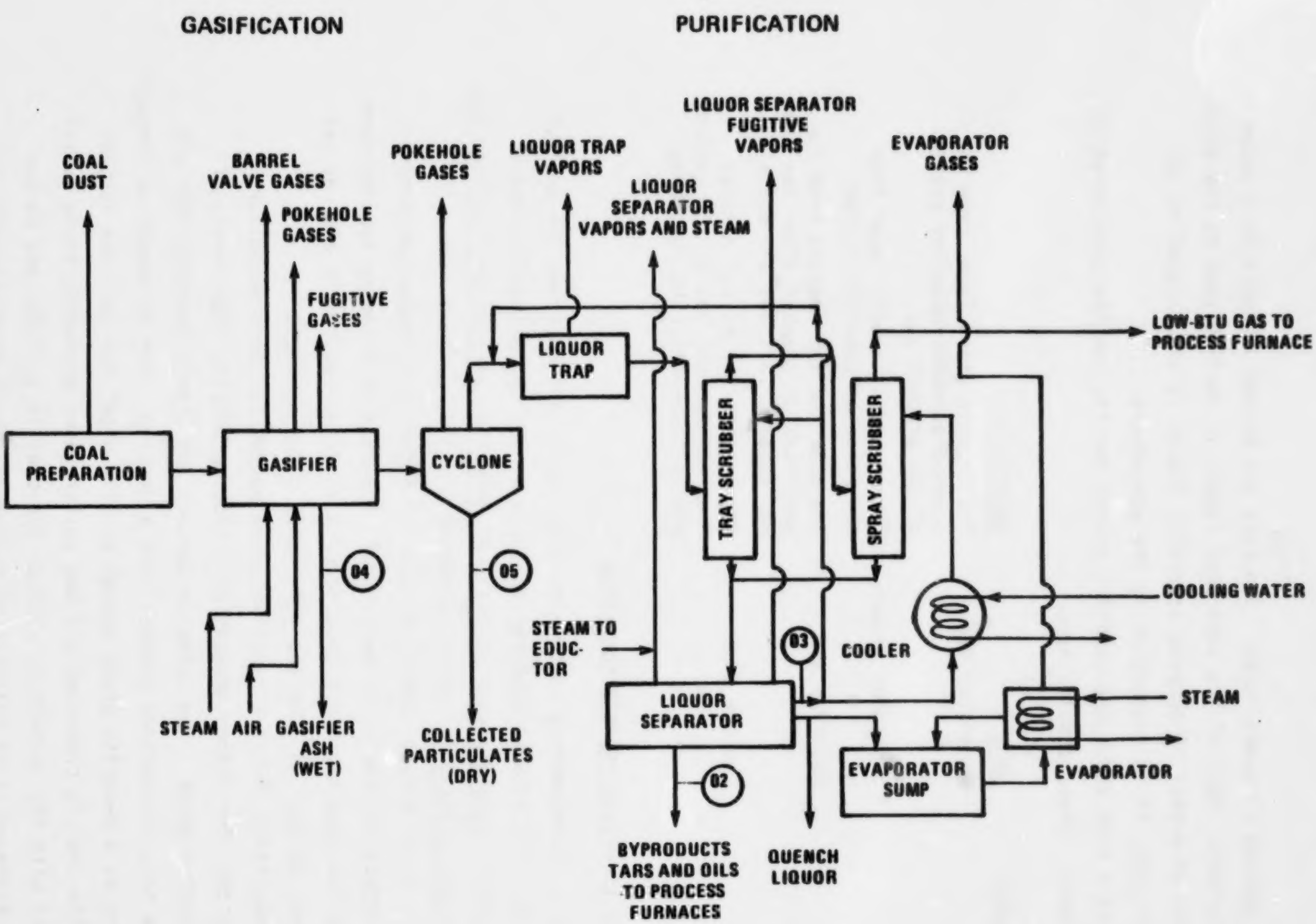
DATA IDENTIFICATION

As previously noted, the raw chemical and biological data interpreted in this task were generated on four environmental assessment studies: The Exxon fluidized-bed combustor miniplant,[4] a coal gasification process,[5] a series of textile plants,[6] and a series of industrial plants.[7] Although a large volume of data was generated from these studies, only Level 1 chemical and biological results were used in the interpretation task. The Level 1 data available for interpretation were further reduced in quantity due to the absence of biological results from some of the samples in which chemical results were generated. Effluent samples in which data were generated by both analyses are included in the total data population and are identified by study in the following sections.

2.1 STUDY 06--CHAPMAN LOW-Btu COAL GASIFIER

Study 06 was performed at a full-scale commercial Chapman low-Btu coal gasification facility. Chemical analysis data were taken from a letter from Dr. Gordon Page of Radian Corporation to Dr. William Rhodes, the EPA Project Officer. The biological data were also taken from unpublished reports sent to Dr. Rhodes by various contractors.

Figure 1 is a schematic of the atmospheric, fixed-bed, air-blown Chapman gasifier sampled in study 06. Coal enters the gasifier through a barrel valve at the top of the gasification chamber, and steam and air are introduced beneath a grating at the bottom of the gasifier. Combustible (product) gases are volatilized from the coal by the steam and heated air. Ash is removed by an ash plow from a water-sealed ash pan at the bottom of the gasifier. The product gas is passed through a cyclone precipitator to remove suspended particulates, then scrubbed in an aqueous scrubber-quencher system to facilitate further cleanup. The liquid used to quench the product gas is directed into a separator where the organic (tar) layer is separated



GASIFICATION
PURIFICATION
COAL DUST
BARREL VALVE GASES
POKEHOLE GASES
FUGITIVE GASES
POKEHOLE GASES
LIQUOR TRAP VAPORS
LIQUOR SEPARATOR VAPORS AND STEAM
LIQUOR SEPARATOR FUGITIVE VAPORS
EVAPORATOR GASES
LOW-BTU GAS TO PROCESS FURNACE
COAL PREPARATION
GASIFIER
CYCLONE
LIQUOR TRAP
TRAY SCRUBBER
SPRAY SCRUBBER
COOLING WATER
COOLER
STEAM TO EDUCTOR
03
04
05
02
LIQUOR SEPARATOR
STEAM
EVAPORATOR SUMP
EVAPORATOR
STEAM
AIR
GASIFIER ASH (WET)
COLLECTED PARTICULATES (DRY)
BYPRODUCTS TARS AND OILS TO PROCESS FURNACES
QUENCH LIQUOR

Figure 1. Process flow diagram for the coal gasification unit (study 06), site A, Level 1 sampling locations.

from the aqueous (liquor) layer. The tars are burned as fuels in a separate process furnace. Most of the separator liquor is recirculated to the scrubbers. When an excess of aqueous separator liquor is accumulated in the evaporator sump, it is evaporated to the atmosphere.

Figure 1 also shows the sampling points for the samples considered in this document. These samples are:

Sample number	Name	Description
02	Separator tar	The organic (tar) layer from the aqueous scrubber-quencher system of the product gas.
03	Separator liquor	The aqueous (liquor) layer from the scrubber-quencher system.
04	Gasifier ash	The coal and ash removed from the gasification chamber after the coal was exposed to steam and hot air.
05	Cyclone dust	The particulate matter removed from the product gas by the cyclone precipitator prior to scrubbing.

2.2 STUDY 10--FLUIDIZED-BED COMBUSTOR

Exxon's fluidized-bed combustion (FBC) miniplant unit was the subject of study 10. The data on chemical analysis were drawn primarily from a draft document, Comprehensive Analysis of Emissions from Exxon Fluidized-Bed Combustion Miniplant Unit, dated September 9, 1977, by J. M. Allen, J. E. Howes, Jr., S. E. Miller, and K. M. Duke of Battelle-Columbus Laboratories, and EPA Project Officer D. B. Henschel.[4] The data on bioassay testing were drawn from the investigator's/contractor's internal reports to EPA, as yet unpublished, as well as from the previously cited document.

A pressurized FBC is a relatively new method for burning sulfur-containing coal for energy generation without producing high levels of effluent sulfur gases. The dolomite sorbent and finely powdered coal are fed into a hot, pressurized chamber over a grating. Air is pumped up through the grating at a velocity great enough to "fluidize" the coal and sorbent bed. As the coal is combusted and the sulfur gases produced, these sulfur gases react with the sorbent to produce nonvolatile sulfides and carbon dioxide. Although it is possible to regenerate these spent sorbents for reuse, producing H_2SO_4, SO_2, or elemental sulfur as byproducts, the regeneration process was not performed in this study.

The 12.5-in. pressurized FBC in this study is located in Linden, New Jersey. Sampling and analyses were performed by Battelle-Columbus Laboratories. Five runs were sampled; all burned Champion Pittsburgh Seam Coal (2 percent sulfur) with dolomite ($CaCO_3$ and $MgCO_3$) sorbent injection. As noted above, sorbent regeneration was not used. Runs 1, 3, 4, and 5 operated at 890°-895° C; Run 2 operated at 805° C. On Runs 2, 4, and 5, a special glass-lined organic module was used for SASS train collection. A thorough Level 1 chemical characterization was performed for Runs 2 and 5 and, in some cases, these values were averaged for comparison with bioassay testing, which was done exclusively on Run 4. Run 4 chemical data were used when available.

Figure 2 is a schematic diagram of the Exxon FBC; samples considered in this project are noted. Other samples were taken in the study but, as previously mentioned, data on these samples were not used because of a lack of biological plus chemical characterization. The samples, numbered by sampling point as in Figure 2 and on the subsequently described coding sheets, are as follows:

Sample number	Name	Description
01	Feed coal	The finely powdered coal fed into the combustion chamber bed.
02	Dolomite	The sorbent material fed into the combustion chamber bed.
03	Fine particulates	The 1μ cyclone catch (particles ≥1μ and <3μ in size) and the filter catch (particles <1μ) from the SASS train.
04	Coarse particulates	The 3μ cyclone catch (particles 3μ-10μ in size) and the 10μ cyclone catch (particles >10μ) from the SASS train.
06	Cyclone dust	The particulates removed from the effluent gas by the second cyclone precipitator.
07	Cyclone dust, leachate	An aqueous leachate of the cyclone dust. For biological tests, the leaching was done by shaking one

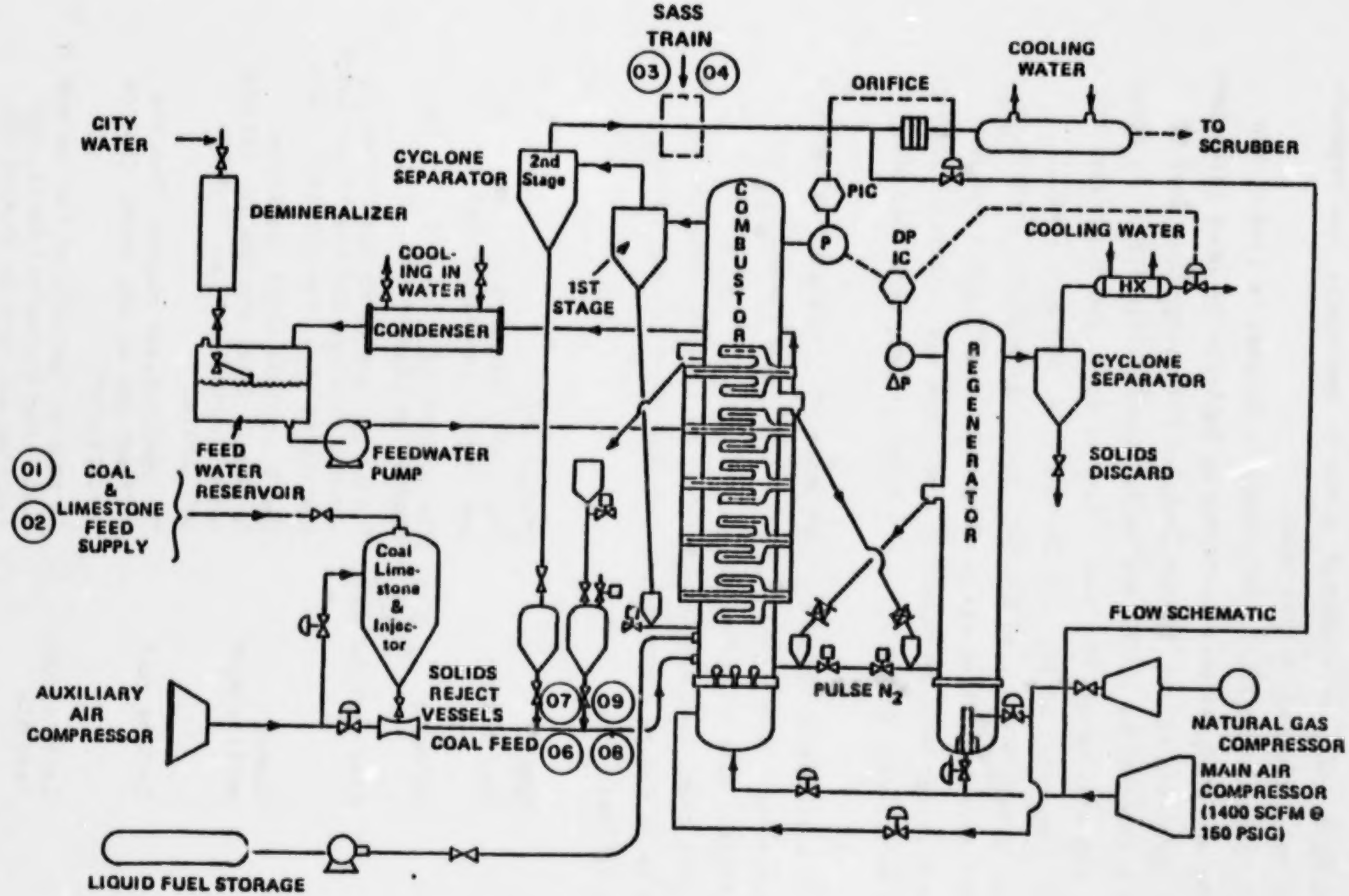

SASS TRAIN
03
04
COOLING WATER
ORIFICE
TO SCRUBBER
CITY WATER
CYCLONE SEPARATOR
2nd Stage
PIC
DEMINERALIZER
C O M B U S T O R
P
DP IC
COOLING WATER
COOL-ING IN WATER
1ST STAGE
HX
CONDENSER
ΔP
R E G E N E R A T O R
CYCLONE SEPARATOR
FEED WATER RESERVOIR
FEEDWATER PUMP
SOLIDS DISCARD
01
COAL & LIMESTONE FEED SUPPLY
02
Coal Lime-stone & Injec-tor
FLOW SCHEMATIC
AUXILIARY AIR COMPRESSOR
SOLIDS REJECT VESSELS
07
09
PULSE N2
NATURAL GAS COMPRESSOR
COAL FEED
06
08
MAIN AIR COMPRESSOR (1400 SCFM @ 150 PSIG)
LIQUID FUEL STORAGE

Figure 2. Exxon fluidized-bed combustion miniplant (study 10), Level 1 sampling locations.

		part solid material with four parts deionized water for 30 min using a high-speed shaker, then decanting and filtering the supernatant. For chemical tests, there were two different leaching procedures used. In the first case, 1 g solid material and 4 mL distilled water were ultrasonically mixed for 1 hr, the mixture was centrifuged, the liquid decanted, another 4 mL water added, and the process repeated 10 times; the first and tenth leachate liquids were chemically analyzed. In the second case, a 50-mL buret was packed with solid material and distilled water was pumped upward through the packed column at about 1 drop/15 s; the first 10 mL of liquid recovered from the top of the column were chemically analyzed. The chemical results used in this study were from the column-leaching procedure.
08	Bed reject material	The coal ash and spent sorbent from the fluidized bed.
09	Bed reject material, leachate	See explanation for sample 07.

2.3 STUDY 15--PARTICULATES FROM VARIOUS INDUSTRIAL PROCESSES

This study was performed to evaluate the newly developed SASS train's capacity for sampling at a variety of industrial source sites. The chemical data were drawn from a report entitled Evaluation of Selected Methods for Chemical and Biological Testing of Industrial Particulate Emissions by H. Mahar of the Mitre Corporation, EPA-600/2-76-137, May 1976.[7] This study utilized only two bioassays, the rabbit alveolar macrophage (RAM) test and the Ames/Salmonella test. The RAM data were obtained from the above-mentioned report and from Jim Campbell and Ned Garrett of Northrop Services. The Ames data were obtained from Dr. David Brusick and Dr. Ross Hart of Litton Bionetics. Since the Ames results were obtained after the data analysis had been performed and since no mutagenic responses were evident in this group of samples, these data were not entered in the data set.

Only particulate samples were collected in this study, and only RAM bioassays and spark source mass spectrometry (SSMS) were performed and entered as part of this study's data base. The particulates were sized via SASS train collection into two categories: particulates <3μ and particulates 3μ-10μ. The following samples were taken:

Sample number	Particle size	Source
01	3μ-10μ	Steel plant--open hearth furnace
02	<3μ	Steel plant--open hearth furnace
03	<3μ	Steel plant--coke oven heater
04	3μ-10μ	Steel plant--basic oxygen furnace
05	<3μ	Steel plant--basic oxygen furnace
06	3μ-10μ	Steel plant--iron sintering
07	<3μ	Steel plant--iron sintering
08	<3μ	Oil-fired power plant
09	<3μ	Copper smelter
10	3μ-10μ	Copper smelter
11	<3μ	Aluminum smelter
12	3μ-10μ	Aluminum smelter
13	<3μ	Ceramics plant
14	3μ-10μ	Ceramics plant
15	<3μ	Sludge incinerator
16	3μ-10μ	Sludge incinerator

2.4 STUDY 19--TEXTILE PLANTS

For Study 19, biological and chemical results were taken primarily from Source Assessment: Textile Plant Wastewater Toxics Study (preliminary draft, December 1977) by G. D. Rawlings of Monsanto Research Corporation, EPA Project Officer Max Samfield.[6] This document covers the sampling efforts and analytical results for the period from January to December 1977, and is part of an ongoing study of the aqueous effluents from 23 textile plants.

This environmental assessment study was conducted concurrently with an effluent guidelines-priority pollutants analysis program and a study by the American Textile Manufacturers Institute (ATMI) to identify the "best available (control) technology economically available" (BATEA) for the 23 plants. The ATMI-BATEA study was already underway when the IERL Level 1 sampling was begun; therefore, only 15 textile plants were sampled and tested for Level 1 chemistry. All 23 plants were sampled and tested for biological parameters.

The Level 1 samples, except those from Plants R and Y, were 8-hr composites taken from the textile plants' wastewater treatment facilities at a location between the clarifier and the chlorine contact basin. Figure 3 shows the sampling locations for these secondary effluent samples.

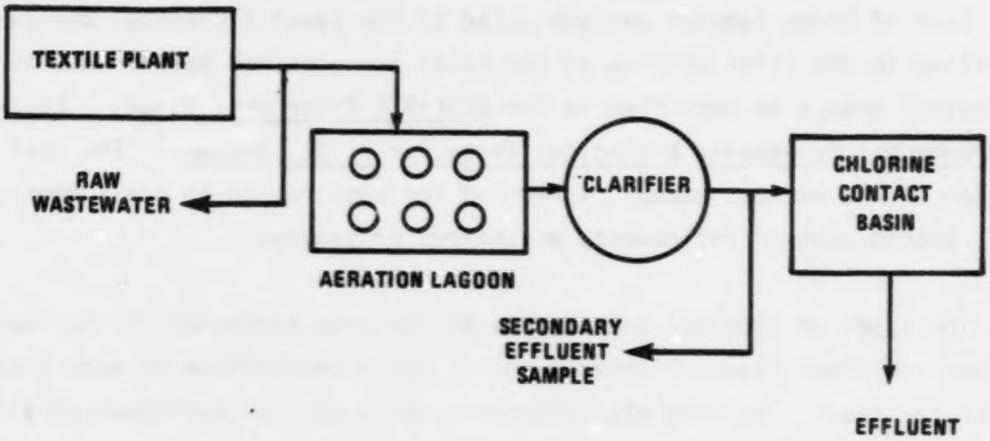

TEXTILE PLANT
RAW WASTEWATER
AERATION LAGOON
CLARIFIER
CHLORINE CONTACT BASIN
SECONDARY EFFLUENT SAMPLE
EFFLUENT

Figure 3. Process flow diagram for the textile plants (study 19). Level 1 sampling locations.

Plant R samples were taken between the aeration lagoon and the settling basin, and Plant Y samples were taken after the finishing pond.

The textile study's samples then fall into three groups:

Sample numbers	Name	Description
OA, OB, OC, OE, OF, OG, OK, OL, ON, OS, OT, OU, OV, OW, OX	Textile plants' secondary effluent	Aqueous effluent after aerator and clarifier (full Level 1 analysis, chemistry and bioassays)
OD, OH, OJ, OM, OP, OZ	Textile plants' secondary effluent	Aqueous effluent after aerator and clarifier (Hg, Sb, and As by AA; and bioassays)
OR, OY	As described in text above	(Hg, Sb, and As by AA; and bioassays)

Each of these samples was subjected to the Level 1 chemical analyses as specified in the first edition of the Level 1 procedures manual[8] and to biological assays as specified in the IERL-RTP Procedures Manual: Level 1 Environmental Assessment Biological Tests for Pilot Studies.[2] The new edition of the biotest manual, scheduled for publication in the summer of 1979, should contain refinements of several procedures.

The types of chemical and biological analyses performed in the four studies are identified in Tables 1 and 2, and a description of each test's output is given. The complete battery of tests was not performed on all samples, so Table 3 lists the individual samples and identifies the analyses that were performed on each sample.

2.5 DESCRIPTION OF SAMPLE DATA FORMATS

To facilitate entry into the computer, reduced data from each effluent sample were entered on Fortran coding sheets. Each sheet received data from only one effluent sample and is therefore identified as a sample data set. This study compared data from 51 data sets (51 effluent samples). A guide for entering both chemical and biological data onto the coding sheet used in this study is given in Table 4. Each of the 31 lines contains an identifier column, followed by 7 columns of parameters. The identifier numbers, making up the first column, reference the line of data (first two digits), the study from which the data are taken (third and fourth digits), and the

TABLE 1. LEVEL 1 BIOLOGICAL ANALYSES

Test	Output
HEALTH EFFECTS	
Ames/Salmonella (Ames)	Mutagenicity to bacterial DNA
Rabbit Alveolar Macrophage (RAM)	Toxicity to mammalian lung cells
WI-38 Human Lung Fibroblast* (WI-38)	Toxicity to human lung cells
Chinese Hamster Ovarian Cell (CHO)	Toxicity to mammalian reproductive cells
Rodent Acute Toxicity (RAT)	Lethality to whole animal (mammal) and behavioral and physiological effects
ECOLOGICAL EFFECTS	
Freshwater algal (FW ALGAL)	Growth inhibition or stimulation to selected freshwater plants
Marine algal (SW ALGAL)	Growth inhibition or stimulation to selected marine plants
Daphnia	Lethality to a freshwater invertebrate animal
Grass shrimp	Lethality to a marine invertebrate animal
Fathead minnow (FW FISH)	Lethality to a freshwater fish
Sheepshead minnow (SW FISH)	Lethality to a marine fish

*The WI-38 Human Lung Fibroblast Test is an optional test in the Level 1 testing protocol. At the present time, the RAM test is used for particulate samples and the CHO test for liquids and extracts. Note that FW refers to freshwater test and SW refers to saltwater test.

TABLE 2. LEVEL 1 CHEMICAL ANALYSES

Test	Output
Spark Source Mass Spectrometry (SSMS)	All elements except H and He
Atomic Absorption Spectrometry (AAS)	Hg, Sb, and As
Infrared Spectrophotometry (IR)	Organic functional groups
Low Resolution Mass Spectrometry (LRMS)	Organic functional groups and some specific compounds
Liquid Chromatographic Separation (LC)	Organic components in 7 separate fractions from the least polar components in fraction 1 to the most polar in fraction 7
Gravimetric Analysis (GRAV)	Weight of nonvolatile organic components
Gas Chromatography--Flame-Ionization Detection (GC-FID) and Total Chromatographable Organics Scheme (TCO)	Weight of volatile organic components
Ion Chromatography (IC)	Identification and quantitation of inorganic anions
Field Gas Chromatography	Identification and quantitation of very volatile components of gaseous effluent streams
Test kits, wet-chemical methods	Identification and quantitation of selected inorganic anions in liquid samples

TABLE 3. SUMMATION OF TEST RESULTS BY STUDY AND BY SAMPLE

	Coal gasifier, study 06					FBC, study 10							Mitre Corporation, study 15	Textile plants, study 19	
	Separator tar	Separator liquor	Gasifier ash	Cyclone dust	Feed coal	Dolomite	Fine particulate	Coarse particulate	Cyclone dust	Cyclone dust leachate	Bed reject	Bed reject leachate	All samples	15 plants*	8 plants†
Analytical test—biological															
Ames	√	√	√	√	√		√	√	√		√			√	
RAM	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
CHO															
RAT		√	√	√	√	√			√		√			√	
FW algal		√								√		√		√	
SW algal		√								√		√			
Daphnia		√								√		√		√	
Grass shrimp		√								√		√		√	
FW fish		√								√		√		√	
SW fish		√												√	
Analytical test—chemical															
SSMS	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
IR	√	√	√	√	√		√	√	√		√			√	
LRMS					√		√	√	√		√			√	
LC	√	√		√	√		√	√	√		√			√	
GRAV	√	√		√	√		√	√	√		√			√	
GC-FID	√	√		√	√		√	√	√		√				
Anions				√	√	√	√	√	√	√	√			√	
Aqueous analysis					√	√	√	√	√	√	√	√		√	

*Plants A, B, C, E, F, G, K, L, N, S, T, U, V, W, X.

†Plants D, H, J, M, P, R, Y, Z.

Note: The WI-38 Human Lung Fibroblast Test is an optional test in Level 1 testing protocol. At the present time, the RAM test is used for particulate samples and the CHO test for liquids and extracts.

TABLE 4. PARAMETER CODE SHEET FOR PILOT STUDIES, LEVEL 1 ENVIRONMENTAL ASSESSMENTS

	1	2	3	4	5	6	7
010000	SAMPLE ID	RAM AT 1000 µg/mL	.	WI-38 AT 600 µL/mL		CHO, MEAN % SURVIVAL	
020000	VIABILITY INDEX @ 1000 µg/mL	ATP–(fg/cell) @ 1000 µg/mL	PROBIT–VIAB.	PROBIT–ATP	AMES1	RAT LD_{50}	OTHER RAT TEST
030000	SOIL MICROCOSM	FW ALGAL	SW ALGAL	FW FISH (24)	FW FISH (48)	FW FISH (96)	DAPHNIA (24)
040000	DAPHNIA (48)	SW FISH (24)	SW FISH (48)	SW FISH (96)	GRASS SHRIMP (24)	GRASS SHRIMP (48)	GRASS SHRIMP (96)
050000	RAT–% INCREASE IN WT.						
060000	U	Th	Bi	Pb	Tl	Hg	Au
070000	Pt	Ir	Os	Re	W	Ta	Hf
080000	Lu	Yb	Tm	Er	Ho	Dy	Tb
090000	Gd	Eu	Sm	Nd	Pr	Ce	La
100000	Ba	Cs	I	Te	Sb	Sn	In
110000	Cd	Ag	Pd	Rh	Ru	Mo	Nb
120000	Zr	Y	Sr	Rb	Br	Se	As
130000	Ge	Ga	Zn	Cu	Ni	Co	Fe
140000	Mn	Cr	V	Ti	Sc	Ca	K
150000	Cl	S	P	Si	Al	Mg	Na
160000	F	B	Be	Li	MEG1	MEG2	MEG3
170000	MEG4	MEG5	MEG6	MEG7	MEG8	MEG9	MEG10
180000	MEG11	MEG12	MEG13	MEG14	MEG15	MEG16	MEG17
190000	MEG18	MEG19	MEG20	MEG21	MEG22	MEG23	MEG24
200000	MEG25	MEG26	Cl^-	F^-	$SO_4^=$	NO_3^-	NO_2^-
210000	$CO_3^=$	$S^=$	LC1	LC2	LC3	LC4	LC5
220000	LC6	LC7	LC8	GC7	GC8	GC9	GC10
230000	GC11	GC12	GC13	Hg-AA	Sb-AA	As-AA	NO_x
240000	O_2	CO_2	SO_2	CO	H_2S-COS	HCN	F_2
250000	Cl_2	Ph	ACIDITY	ALKALINITY	BOD	COD	DO
260000	CONDUCTIVITY	DISSOLVED SOLIDS	SUSPENDED SOLIDS	Cr^{++}	$SO_3^=$	H_2S	ORGANICS
270000	NH_3	CN^-	SCN^-				
280000	TA1535-	TA1535+	TA1537-	TA1537+	TA98-	TA98+	TA100-
290000	TA100+	TA1538-	TA1538+				
300000	AMES2	RAM	WI-38	CHO	RODENT	FW ALGAL	GRASS SHRIMP
310000	FW FISH	DAPHNIA					

sample number (fifth and sixth digits). For example, 031001 refers to data line 3 from study 10, sample 01.

The key to study identifiers is:

06: Coal gasification

10: Exxon's FBC miniplant

15: Ten industrial sources, SASS evaluation

19: Textile plant effluents.

Each piece of data for a study is identified by its sample code number and column number. For example, 110605-column 2 identifies the amount of silver found in the Radian Cyclone Dust sample. To further identify the data, the units for each parameter are noted in Table 5. Looking at line 11, column 2, μg/g is the unit to which all data on silver content have been reduced.

The sample identifier (sample ID) is found on line 1, column 2 of each coding sheet. It is limited to nine characters. Table 6 provides a description of the coded sample identifiers. Appendix A lists the entire data base by individual sample data sets.

It should be noted that other, more thorough data formats for the IERL Environmental Assessment Program are being developed. Mr. Gary Johnson of the IERL Special Studies Staff is developing detailed data entry forms that are compatible with the EPA UNIVAC 1100 computer system. This new data analysis and storage system, the Environmental Assessment Data System (EADS), will contain much supportive information; e.g., plant conditions at the time of sampling, atmospheric conditions, date, run number, personnel identification, and documentation of any anomalies. At the time of the preparation and execution of this study, the EPA data systems were completed and operational only for fine particulates.[9] [10] As part of this task, the authors cooperated with Mr. Johnson in the design of input for bioassay data entry forms and shared information on other sampling/analytical types that were available from this study.

TABLE 5. UNIT CODE SHEET FOR PILOT STUDIES, LEVEL 1 ENVIRONMENTAL ASSESSMENTS

	1	2	3	4	5	6	7
01		X OF VIA. & ATP AS A % OF CONTROLS		X OF VIA. & ATP AS A % OF CONTROLS PROBIT 1/LD$_{50}$		MEAN % SURVIVAL AT 200 μL/mL	
02	← μg/mL →	← μg/mL →	PROBIT 1/LD$_{50}$		← 1-4 →	← g/kg →	← Σ OF # OF OCCURRENCES →
03	Σ OF # OF POSITIVE PARAMETERS	← 14 DAY EC$_{20}$% →	← EC$_{50}$%, 96 HR. →	← LC$_{50}$%	→	→	← EC$_{50}$% →
04	← EC$_{50}$% →	← LC$_{50}$%	→	→	→	→	→
05	← %, g/100 g →						
06	μg/g	→	→	→	→	→	→
07	μg/g	→	→	→	→	→	→
08	μg/g	→	→	→	→	→	→
09	μg/g	→	→	→	→	→	→
10	μg/g	→	→	→	→	→	→
11	μg/g	→	→	→	→	→	→
12	μg/g	→	→	→	→	→	→
13	μg/g	→	→	→	→	→	→
14	μg/g	→	→	→	→	→	→
15	μg/g	→	→	→	→	→	→
16	μg/g	→	→	→	mg/g	→	→
17	mg/g	→	→	→	→	→	→
18	mg/g	→	→	→	→	→	→
19	mg/g	→	→	→	→	→	→
20	mg/g	→	WT. %	→	→	→	→
21	WT. %	→	μg/g	→	→	→	→
22	μg/g	→	→	→	→	→	→
23	μg/g	→	→	→	→	→	← ppm →
24	%	→	ppm	→	→	→	→
25	← ppm →	← 1-14 →	← g/m^3	→	→	→	→
26	← μmhos @ 25° →	g/m^3	→	→	→	→	→
27	← g/m^3	→	→				
28	MAXIMUM VALUE OF REVERTANTS PER PLATE/REVERTANTS IN CONTROL	→	→	→	→	→	→
29	FOR ALL AMES' STRAINS W & W/O METABOLIC ACTIVATION →						
30	LITTON/BRUSICK'S INTERPRETATION, WITH NO DETECTABLE TOXICITY = 1, LOW TOXICITY = 2, MODERATE TOXICITY = 3,						
31	HIGH TOXICITY = 4						

TABLE 6. SAMPLE IDENTIFICATION CODE

Sample code no.	Sample name	Description
010602	SEPARATAR	Coal gasifier separator tar
010603	SEPARALIQ	Coal gasifier separator liquor
010604	GASIFLASH	Coal gasifier (unground) ash
010605	CYCLODUST	Coal gasifier cyclone dust
011001	FEEDCOAL	FBC feed coal
011002	DOLOMITE	FBC dolomite
011003	FINEPART	FBC fine particulates (1μ cyclone and filter)
011004	CORSEPART	FBC coarse particulates (3μ and 10μ cyclone)
011006	CYCLODUST	FBC cyclone dust
011007	CYCLOLEACH	FBC cyclone dust leachate
011008	BEDREJECT	FBC bed reject
011009	BEDLEACH	FBC bed reject leachate
011501	STEEL3MIC	Steel plant—open hearth furnace (3μ-10μ particulates)
011502	STEEL1MIC	Steel plant—open hearth furnace (<3μ particulates)
011503	COKE1MICR	Steel plant—coke oven heater (<3μ particulates)
011504	STEELO3MI	Steel plant—basic oxygen furnace (3μ-10μ particulates)
011505	STEELO1MI	Steel plant—basic oxygen furnace (<3μ particulates)
011506	IRUN3MICR	Steel plant—iron sintering (3μ-10μ particulates)
011507	IRUN1MICR	Steel plant—iron sintering (<3μ particulates)
011508	OIL1MICRO	Oil-fired power plant (<3μ particulates)
011509	COPPER1MI	Copper smelting (<3μ particulates)
011510	COPPER3MI	Copper smelting (3μ-10μ particulates)
011511	ALSM1MICR	Aluminum smelting (<3μ particulates)
011512	ALSM3MICR	Aluminum smelting (3μ-10μ particulates)
011513	CERAM1MIC	Ceramics plant (<3μ particulates)
011514	CERAM3MIC	Ceramics plant (3μ-10μ particulates)
011515	SLUDGE1MI	Sludge incinerator (<3μ particulates)
011516	SLUDGE3MI	Sludge incinerator (3μ-10μ particulates)
01190A	PLANT A	Textile effluent—plant A
01190B	PLANT B	Textile effluent—plant B
01190C	PLANT C	Textile effluent—plant C
01190D	PLANT D	Textile effluent—plant D
01190E	PLANT E	Textile effluent—plant E
01190F	PLANT F	Textile effluent—plant F
01190G	PLANT G	Textile effluent—plant G
01190H	PLANT H	Textile effluent—plant H
01190I	PLANT I	Textile effluent—plant I
01190J	PLANT J	Textile effluent—plant J
01190K	PLANT K	Textile effluent—plant K
01190L	PLANT L	Textile effluent—plant L
01190M	PLANT M	Textile effluent—plant M
01190N	PLANT N	Textile effluent—plant N
01190O	PLANT O	Textile effluent—plant O
01190P	PLANT P	Textile effluent—plant P
01190Q	PLANT Q	Textile effluent—plant Q
01190R	PLANT R	Textile effluent—plant R
01190S	PLANT S	Textile effluent—plant S
01190T	PLANT T	Textile effluent—plant T
01190U	PLANT U	Textile effluent—plant U
01190V	PLANT V	Textile effluent—plant V
01190W	PLANT W	Textile effluent—plant W
01190X	PLANT X	Textile effluent—plant X
01190Y	PLANT Y	Textile effluent—plant Y
01190Z	PLANT Z	Textile effluent—plant Z

SECTION 3

QUANTIFICATION OF DATA

The effluents and feedstocks sampled during the four EA pilot studies were liquids, solids, and slurries. This variation resulted in analytical results being reported in different units from study to study and sample to sample. For example, analytical results of spark source mass spectrometry (SSMS) generated on solid samples were generally reported in micrograms (μg) of element per gram (g) of sample. Conversely, SSMS results on liquid samples were reported in micrograms of element per liter (L) of sample. This variability in the data units from different analytical tests was resolved by choosing suitable units in which each test should be reported and then converting data across all studies into uniform units. Data in consistent units could then be entered into the program as absolute numbers for comparison. Data thus entered include results for SSMS, anion, gas chromatography (GC), atomic absorption (AA), and aqueous analyses. Results of organic analysis (liquid chromatography [LC] fraction weights, infrared spectrophotometry [IR], and low resolution mass spectrometry [LRMS]) were summarized by use of a method explained in the subsection of this section on organic analysis.

Bioassay results were quantified by use of the actual LC_{50} and LD_{50} values as well as by a grouping model designed by Litton Bionetics. Comparison of the data quantified by these two methods provided a quality assurance (QA) check to insure that the grouped data truly represented the actual results.

3.1 CHEMICAL RESULTS--INORGANIC

3.1.1 Spark Source Mass Spectrometry (U to Li)

In a given sample, data for any element present at a level above the minimum detection limit were converted, where necessary, to micrograms per gram of effluent sample (ppm by weight). Each elemental concentration less than the minimum detection limit was recorded as a value equal to one-half the minimum detection limit; these minimum detection limit data were further coded by the use of a negative sign preceding each value on the data page. The absolute values of all numbers entered in the data set were used for computations in this study, but in future studies with larger data bases, this coding would allow other options, such as eliminating minimum detection limit values or setting these values equal to zero.

3.1.2 Anion Analysis (Cl^-, F^-, $SO_4^=$, NO_2^-, $CO_3^=$, S^-)

Reported values were converted to weight percent (g/100 g), if necessary, and entered for each sample in which data were generated.

3.1.3 Atomic Absorption (As, Sb, Hg)

Absolute values were converted to micrograms per gram, if necessary, and entered for each sample in which data were generated.

3.1.4 Chemiluminescence (NO_x)

No data were available for samples in this data set.

3.1.5 ORSAT (O_2)

No data were available for samples in this data set.

3.1.6 Gas Chromatography (CO_2, SO_2, CO, H_2S-CO_3, HCN, F_2, Cl_2)

No data were available for samples in this data set.

3.1.7 Aqueous Analysis

Data were available only on the textile study. Absolute values were entered in grams per cubic meter (ppm by weight) for each sample.

3.2 CHEMICAL RESULTS--ORGANIC

Liquid chromatographic fraction gravimetric weights were entered directly into the data set with only unit changes, where needed. Volatile (TCO) weights were not generated in these studies. Therefore, any subsequent correlations or other data manipulations consider only the nonvolatile (gravimetric [GRAV]) portions of these samples. The quantification of organic results from written form (i.e., alcohols, $-CH_3$) to multimedia environmental goals (MEG) categories (categories of similar organic compounds such as amines and benzene derivatives) was more complex. All organic analyses results (LC, IR, and LRMS) were used to determine the weights of MEG categories found in each sample. For reference, Table 7 gives the chemical categories found in each MEG category.

Three separate methods were used for the quantification of organic analytical results into MEG categories, depending on the amount of available information:

I. In cases where only IR and LC/GRAV results were available, the following procedure was used:
   - A. List categories that could possibly be present in a given LC fraction.
   - B.. Examine IR report for that LC fraction. Examine LC/GRAV report for that LC fraction.
   - C. Assign a weight equal to one-half the GRAV weight to each compound indicated as possibly present by IR.
   - D. Assign a weight equal to one-tenth the GRAV weight to each compound indicated as not present by IR.
   - E. Total the assigned weights by MEG category.

II. In cases where LRMS and LC/GRAV results are available, this procedure was used:
   - A. List the major categories and their reported intensities from the LRMS report.
   - B. Total the intensity values.
   - C. Estimate weights as fractional parts of the total LC/GRAV weight:

$$\frac{\text{Intensity of category X}}{\Sigma\ \text{Intensities of all categories in fraction}} \times \begin{array}{c}\text{Total GRAV weight}\\ \text{of fraction}\end{array} = \begin{array}{c}\text{Estimated weight}\\ \text{of category X}\end{array}$$

   - D. Total the estimated category weights by MEG category.

III. The following procedure was applied in cases where there was a very small amount of organic material in a given fraction and, as a result, no LRMS was run, but LRMS spectra were available on adjacent fractions:
   - A. Compare the IR spectra of adjacent fractions with the IR spectrum of the fraction under consideration.
   - B. Match with the most similar fraction.

TABLE 7. ORGANIC CATEGORIES IN THE MEG LIST

1	Aliphatic hydrocarbons
2	Halogenated aliphatic hydrocarbons
3	Ethers
4	Halogenated ethers
5	Alcohols
6	Glycols, epoxides
7	Aldehydes, ketones
8	Carboxylic acids and derivatives
9	Nitriles
10	Amines
11	Azo compounds, hydrazine, and derivatives
12	Nitrosamines
13	Mercaptans, sulfides and disulfides
14	Sulfonic acids, sulfoxides
15	Benzene, substituted benzene hydrocarbons
16	Halogenated aromatic hydrocarbons
17	Aromatic nitro compounds
18	Phenols
19	Halophenols
20	Nitrophenols
21	Fused aromatic hydrocarbons
22	Fused nonalternant polycyclic hydrocarbons
23	Heterocyclic nitrogen compounds
24	Heterocyclic oxygen compounds
25	Heterocyclic sulfur compounds
26	Organometallics

C. Assign the same weight distribution (as determined in II, above) to the fraction under consideration as was calculated for the most similar adjacent fraction.

The revised Level 1 procedures manual (Chapter 9)[1] gives detailed instructions and examples for the above calculations. This method of summarizing the organic data was originally suggested by Dr. Judi Harris and Dr. Philip Levins of Arthur D. Little, Inc.

3.3 BIOASSAY RESULTS

Bioassays were quantified by two methods. One method involved an assignment of "nondetectable," "low," "moderate," or "high" to each biological response. This method, proposed by Dr. David Brusick of Litton Bionetics,[11] is referred to hereafter as the Litton quantification scheme. Levels of response are assigned to bioassays on the basis of the concentration at which a biological system is affected by a sample relative to the maximum applicable dose (MAD) of sample possible for that system. The levels of toxicity assigned by Litton Bionetics are: (1) no detectable toxicity if no significant response occurs at the MAD; (2) low toxicity if the response occurs at a concentration between the MAD and 1/10 MAD; (3) moderate toxicity if the response occurs at a concentration between 1/10 MAD and 1/100 MAD; and (4) high toxicity if the response occurs at a concentration less than 1/100 MAD.

The MAD concept must be applied differently to each biological test. Table 8 gives response ranges and maximum applicable doses for several of the Level 1 bioassays. Table 9 identifies a variety of possible reporting units and illustrates how they can be quantified into toxicity levels. In the Ames test, the criteria suggested by Brusick and used herein for a positive (mutagenic) response is a ratio of test revertants to control revertants greater than 3 for strains TA1535, TA1537, or TA1538, or a ratio greater than 2 for strains TA98 or TA100, plus an increasing dose-response relationship over three successive dose ranges.

The second method used to quantify the bioassay results was through the use of the originally reported results on many of the parameters measured in each bioassay. For example, the RAM test system was tested for four major parameters: cell count, viability, protein, and ATP at several dosage

TABLE 8. RESPONSE RANGES FOR RANKING OF VARIOUS BIOTESTS*

			Response ranges			
Assay	Activity measured	MAD	High	Moderate	Low	Not detectable
Health Tests						
Ames	Mutagenesis	5 mg/plate or 500 μL/plate	<0.05 mg or <5 μL	0.05-0.5 mg or 5-50 μL	0.5-5 mg or 50-500 μL	ND at >5 mg or ND at >500
RAM, CHO, WI-38	Lethality (LC_{50})	1,000 μg/mL or 600 μL/mL	<10 μg or <6 μL	10-100 μg or 6-60 μL	100-1,000 μg or 60-600 μL	LC_{50} > 1,000 μg or LC_{50} > 600 μL
Rodent	Lethality (LD_{50})	10 g/kg or 10 mL/kg	<0.1	0.1-1.0	1-10	LD_{50} > 10
Aquatic						
Algae	Growth inhibition EC_{50}	100 mg/L	<1	1–10	10–100	EC_{50} > 100
Fish	Lethality LC_{50}	100 mg/L	<1	1–10	10–100	LC_{50} > 100
Invertebrate	Lethality LC_{50}	100 mg/L	<1	1–10	10–100	LC_{50} > 100

MAD = Maximum applicable dose (technical limitations).
LD_{50} = Calculated dosage expected to kill 50% of population.
LC_{50} = Calculated concentration expected to kill 50% of population.
EC_{50} = Calculated concentration expected to produce effect in 50% of population.
ND = Not detectable.

*Subsequent to the completion of this work, the response ranges for the aquatic tests were redefined based on recommendations from EPA ecologists. The new ranges are:

	MAD	High	Moderate	Low	Not detectable
Algae	1,000 mg/L or 100%	<20% or <200 mg	20-75% or 200-750 mg	75-100% or 750-1,000 mg	EC_{50} > 100% or EC_{50} > 1,000 mg
Fish	1,000 mg/L or 100%	<20% or <200 mg	20-75% or 200-750 mg	75-100% or 750-1,000 mg	LC_{50} > 100% or LC_{50} > 1,000 mg
Invertebrate	1,000 mg/L or 100%	<20% or <200 mg	20-75% or 200–750 mg	75-100% or 750-1,000 mg	LC_{50} > 100% or LC_{50} > 1,000 mg

TABLE 9. QUANTIFICATION OF BIOTEST RESULTS, EXAMPLES

Biotest	Reported units	Reported value(s)*	Assigned toxicity level*
AMES	$\frac{\text{Max. \# Revertants, Test}}{\text{\# Control Revertants}}$	1.9	N
RAM			
Viability Index	EC_{20}% (24 hr)	13.3	M
ATP	EC_{20}% (24 hr)	3.8	
WI-38			
Viability Index	As % of control at maximum dose	56.1	L
ATP	As % of control at maximum dose	11.2	
RAT			
Viability Index	LD_{50}, g/kg	> 10	N
Other Effects	Distended caecum, weight loss in 5 ♀	6 Effects	
FW ALGAL	EC_{20}% (14 day)	2	M
DAPHNIA	EC_{50}% (48 hr)	0	H
FW FISH	LC_{50}% (96 hr)	48.8	L
SW ALGAL	EC_{50}% (96 hr)	2.3	M
GRASS SHRIMP	LC_{50}% (96 hr)	26.3	L
SW FISH	LC_{50}% (96 hr)	47.5	L

FW = Freshwater.
SW = Saltwater (marine).
N = No detectable toxicity.
L = Low toxicity rating.
M = Moderate toxicity rating.
H = High toxicity rating.

*Data in these columns are sample data from Plant N.

levels. After discussion with biologists familiar with the system, it was decided that five values might be of special interest in this data set. These values were:

1. Viability index at the MAD of 1,000 μg/mL:
   $$\text{Viability index} = \text{Viability (as percentage of control)} \times \frac{\#\text{ of cells in test culture}}{\#\text{ of cells in control culture}} .$$
2. ATP at 1,000 μg/mL.
3. The average of 1 and 2, above.
4. The LD_{50} value, as determined from probit analysis of the dose-response relationship between pollutant dosage and viability. Probit analysis was performed via the Statistical Analysis System (SAS). The methods for probit analysis are detailed in reference 12. The reciprocal of the LD_{50} value was entered ($1/LD_{50}$) so that toxic responses would exhibit a positive slope and a positive correlation coefficient in the subsequent statistical analysis. Probit analysis is discussed in more detail in the next section of this document.
5. $1/LD_{50}$ when a dose-response relationship between pollutant level and ATP level was considered as in 4.

Efforts were directed at identifying the presence of any parameter that would correlate with other bioassays or chemical assays. Quantification of the individual biotests, using the reported or raw data, is discussed in the following sections.

3.3.1 Microbial Mutagenicity (Ames)

Two different methods of quantifying Ames test data were used and both were based on the maximum mutagenic ratio, herein defined as the ratio of the maximum average number of revertant colonies in any experimental dose to the average number of spontaneous revertants in control cultures. The maximum mutagenic ratio was determined both with S-9 (rat liver microsomal) activation and without S-9 activation. Five different strains of *Salmonella typhimurium* were used in the test series; therefore 10 ratios were generated.

A second method of interpreting these results was to group results in a manner slightly different from the Litton grouping noted above. A maximum mutagenic ratio less than or equal to 3 was given a value of 1 in the data set. A maximum mutagenic ratio greater than 3 but less than or equal to 4 was given a value of 2. A ratio greater than 4 but less than 5 was coded as 3. All ratio values equal to or greater than 5 were quantified as 4.

3.3.2 Rabbit Alveolar Macrophage (RAM)

The quantification methods for this test were described as an example in Section 3.3.

3.3.3 WI-38 Human Lung Fibroblast (WI-38)

The parameters measured were cell count, viability, protein content, and ATP content as in the RAM test. Because the WI-38 bioassays were performed on so few samples, only one value was entered in the data set: the average of (1) the viability index at the MAD (600 μL/mL) and (2) the ATP content at the MAD. In both the RAM and the WI-38 systems, it was observed that ATP was a more sensitive parameter than protein; that is, ATP levels showed a greater amplitude of response than protein levels and ATP responses were generally noticed at lower dosage levels.

3.3.4 Chinese Hamster Ovarian Cell Clonal Assay (CHO)

The average of replicates of the percent survival figure (number of live cells as a percentage of the total number of cells) at the MAD (200 μL/mL) was entered into the data set.

3.3.5 Rodent Acute Toxicity (RAT)

Three means of quantifying the data from this bioassay were employed. First, the LD_{50} value was entered, but because no lethality was observed in any samples at the maximum dosage of 10 g of sample (by gavage) per kilogram of rodent body weight, this did not seem to be a good, discriminating quantification method. A close examination of the raw data (the investigators' laboratory reports) showed many atypical behavioral and physiological responses observed in experimental rats fed the various effluent samples. These atypical responses included reduced activity immediately after dosing, soft stools, a dark red material around the nose or eyes, eye irritation, rough appearance of the ventricles of the heart, abnormal breathing sounds after dosing, abnormal penile discharge, and hair loss in the inguinal region and the area around the eye.

The second parameter entered in the data set for the RAT test was the sum of all abnormal responses noted by the investigator for all 10 rats in the test group; it was possible for this second parameter to exceed 10 if more than one atypical response was noted in a single test animal.

The third means of quantifying a sample's effect on a rat was based on body weight. An expected weight gain was observed in the control group, indicative of the normal rodent growth pattern of continuous weight gain. For each group of 10 experimental animals (five females, five males), the percent gain in body weight was calculated:

$$\frac{\dfrac{\text{Final weight males} - \text{Initial weight males}}{\text{Initial weight males}} + \dfrac{\text{Final weight females} - \text{Initial weight females}}{\text{Initial weight females}}}{2} \times 100 = \text{average percent weight gain.}$$

3.3.6 Freshwater Algal Test (FW Algal)

The original investigators' reported EC_{20} value (reported as percentage of effluent sample in the dilution water media) was encoded in the data set. The effect measured was inhibition of growth, as measured by chlorophyll content of the experimental culture compared to chlorophyll content of the control. The EC_{20} was calculated from chlorophyll measurements taken on the fourteenth day. A standard EC_{50} value was not used because the very low toxicity of many samples from the textile study would have prohibited discrimination between samples using the EC_{50}; that is, all samples with less than 50 percent growth inhibition would appear to be the same numerically.

3.3.7 Marine Algal Test (SW Algal)

Again, growth inhibition was the effect measured. The EC_{50} value after 4 days of testing was the value entered into the data set.

3.3.8 Daphnia

Lethality, or apparent death as measured by immobility after gentle prodding, was the effect of interest. As reported by the original investigator, the EC_{50} was entered into the data set as percentage of effluent sample concentration in diluent aqueous medium after 24 hr and again after 48 hr of testing.

3.3.9 Grass Shrimp

The original investigators' reported LC_{50} values (lethality after 24, 48, and 96 hr) were entered into the data set as percentages of effluent sample concentration in diluent aqueous medium.

3.3.10 Fathead Minnow Test (FW Fish)

The original investigators' reported LC_{50} values (after 24, 48, and 96 hr) were entered into the data set as percentages of effluent.

3.3.11 Sheepshead Minnow Test (SW Fish)

The original investigators' reported LC_{50} values (after 24, 48, and 96 hr) were entered into the data set as percentages of effluent.

Table 10 lists the original results from each study used in this interpretation, the quantification method used to reduce all the results into equivalent units suitable for comparisons, and the coded name assigned to each value for computer encoding and entry.

TABLE 10. QUANTIFICATION OF DATA

Study	Original results	Quantification		Computer-coded final results
	RAM Cytotoxicity*			
6	Cyclone dust Gasifier ash (unground)	**Northrop Data:** Viability Index, mean of 6 repetitions @ 1,000 μg/mL ATP as % control, mean of 6 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
10	Fine particulates, cyclone dust, bed reject, coarse particulates, coal, dolomite	**Northrop Data:** Viability Index, mean of 6 repetitions @ 1,000 μg/mL ATP as % control, mean of 6 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM
6	Separator tar	**ADL Data:** Viability Index, mean of 2 repetitions @ 1,000 μg/mL ATP as % control, mean of 2 repetitions (VIABAND + ATP) ÷ 2	= = =	VIABAND ATP RAM 1000
6	Separator liquor	**ADL Data:** Viability Index, mean of 2 repetitions @ 600 μL/mL ATP as % control, mean of 2 repetitions (VIABAND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
10	Cyclone dust leachate Bed reject leachate	**Northrop Data:** Viability Index, mean of 5 repetitions @ 600 μL/mL ATP as % control, mean of 5 repetitions (VIABAND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
19	Plants L, M, R	**Northrop Data:** Viability Index, mean of 3 repetitions @ 600 μL/mL ATP as % control, mean of 3 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
6	Cyclone dust Gasifier ash (unground)	**Northrop Data:** Viability Index, mean of 6 repetitions @ 1,000 μg/mL ATP as % control, mean of 6 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
10	Fine particulates, cyclone dust, bed reject, coarse particulates, coal, dolomite	**Northrop Data:** Viability Index, mean of 6 repetitions @ 1,000 μg/mL ATP as % control, mean of 6 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
6	Separator tar	**ADL Data:** Viability Index, mean of 2 repetitions @ 1,000 μg/mL ATP as % control, mean of 2 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
6	Separator liquor	**ADL Data:** Viability Index, mean of 2 repetitions @ 600 μL/mL ATP as % control, mean of 2 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000

*The RAM 1000 parameter includes data on leachates (tested at 600 μL/mL) and on solids (tested at 1,000 μg/mL).

(continued)

TABLE 10 (continued)

Study	Original results	Quantification		Computer-coded final results
	RAM Cytotoxicity* (con.)			
10	Cyclone dust leachate Bed reject leachate	**Northrop Data:** Viability Index, mean of 5 repetitions @ 600 μL/mL ATP as % control, mean of 5 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM 1000
19	Plants L, M, R	**Northrop Data:** Viability Index, mean of 3 repetitions @ 600 μL/mL ATP as % control, mean of 3 repetitions (VIABIND + ATP) ÷ 2	= = =	VIABIND ATP RAM [illegible]00
19	Plant N	Same as Plants L, M, R but only 2 repetitions	=	VIABIND
15	Viability Index @ 1,000 μg/mL	Entered as reported		
	WI-38			
19	WI-38 @ 600 μL/mL Plants L, M, N, R	[Viability Index (mean of 3 repetitions @ 600 μL/mL) plus ATP % (mean of 3 repetitions)] divided by 2	=	WI 38600
	CHO			
19	Mean percent survival Plants L, M, N, R, D, J, H	Mean of 3 repetitions	=	CHOMPS
	RAM			
6,10,19	Viability Index, mean at variable doses	Probit analysis by the Statistical Analysis System (SAS) program. EC_{50} values were calculated and their reciprocal values entered	=	PROB VI
6,10,19	ATP, mean at variable doses	Probit analysis by the Statistical Analysis System (SAS) program. EC_{50} values were calculated and their reciprocal values entered	=	PROB VI
	AMES			
6,10,19	Control and revertant colonies at variable doses across several strains with and without metabolic activation (S-9)	The largest ratio of revertant to control colonies across all strains reported. Ratios were grouped such that ratio values < 3 = 1, values between 3 and 4 = 2, values between 4 and 5 = 3, and values > 5 = 4.	=	AMES 1
	RAT			
6,19	Rodent Acute Toxicity (RAT) LD_{50}'s	LD_{50} values entered as reported. If no response @ the maximum dose, that dose was entered	=	RAT LD_{50}
6,19	Behavioral and physiological determinations	Sum of atypical responses, e.g., hair loss = 1 lethargy = 1 Total = 2 entered	=	OTHRAT

(continued)

TABLE 10 (continued)

Study	Original results	Quantification		Computer-coded final results
	ALGAL			
6,10,19	Liquid sample only—freshwater algal reported values as % effluent that caused an EC_{20}; parameter measured was inhibition of growth as measured by chlorophyll content after 14 days.	EC_{20} values entered. If EC_{50} reported, linear extrapolations to EC_{20} by the original investigators performed and results entered	=	FW ALGAL
6	Separator liquor—saltwater algal reported value as % effluent that caused an EC_{50}. Parameter measured was inhibition to growth as measured by chlorophyll content after 4 days	EC_{50} values entered	=	SW ALGAL
	FRESHWATER FISH			
6,10	Liquid samples only—24- and 48-hr LC_{50} values reported	LC_{50} values entered	=	FW FSH 24 FW FSH 48
6,10,19	Liquid samples only—96-hr LC_{50} values reported	LC_{50} values entered	=	FW FSH 96
	DAPHNIA			
6,10	Liquid samples only—24- and 48-hr EC_{50} reported; immobility measured	EC_{50} values entered	=	DAPH 24 DAPH 48
19	48-hr EC_{50} reported	EC_{50} values entered	=	DAPH 48
	SALTWATER FISH			
6,10,19	Liquid samples only—24-, 48- and 96-hr LC_{50} values reported; lethality measured	LC_{50} values entered	=	SW FSH 24 SW FSH 48 SW FSH 96
	GRASS SHRIMP			
6,10,19	Liquid samples only—24-, 48- and 96-hr LC_{50} reported; lethality measured	LC_{50} values entered	=	GSHMP 24 GSHMP 48 GSHMP 96
	RAT WEIGHT			
6,19	Mean body weights of males and females after 14 days reported	Combined average percent weight increase entered	=	RATWT

(continued)

TABLE 10 (continued)

Study	Original results	Quantification		Computer-coded final results
	SSMS			
6,10,15,19	Weight of element per unit of sample	Converted all results to $\mu g/g$ ($g/m^3 = mg/L = \mu g/g$)	=	LNU to LNLI*
	MEG CATEGORIES			
6	Concentrations of organics by MEG category	Entered as reported by the contractor	=	LNMEG 1-LNMEG 26 (mg/g)* (see Table 7)
10	IR and LC/GRAV DATA	Procedures, as specified in Chapter 9 of the IERL-RTP revised Level 1 procedures manual, were followed: For each LC fraction: (1) The IR and LC/GRAV reports were examined (2) IR functional groups and/or compounds were assigned to MEG chemical categories (3) Each functional group and/or compound found by IR was given 50% of the LC/GRAV weight (unless only one compound was found, in which case it was given 100% of the LC/GRAV weight) (4) From a table in the procedures manual, a list of possible compounds eluting in each LC fraction was examined (5) Possible compounds not found by IR analysis were assigned 10% of the LC/GRAV weight This procedure was repeated for each LC fraction, then the MEG category weights were totalled across fractions and entered as sample totals in the Fortran format	=	LNMEG 1-LNMEG 26 (mg/g)* (see Table 7)
19	IR, LRMS, and LC/GRAV DATA	Procedures, as specified in Chapter 9 of the revised IERL-RTP Level 1 procedures manual, were followed: For each LC fraction with LRMS data: (1) The LRMS and LC/GRAV reports were examined (2) Intensity values for major categories were totalled (3) Weights were estimated as fractional parts of the total LC/GRAV weight: $\frac{\text{Intensity of category/compound X}}{\Sigma\ \text{Intensities of all category/compounds in fraction}} \times \text{Total weight of fraction} = \text{Estimated weight of category/compound X}$		

(continued)

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*In showing an element or compound abbreviation, the initial letters "LN" indicate that a logarithmic transformation has been performed on the data. For ease of identification, "LN" is omitted from the abbreviation after this table.

TABLE 10 (continued)

Study	Original results	Quantification		Computer-coded final results†
19	IR, LRMS, and LC/GRAV DATA (con.)	For each LC fraction with only IR data: (1) IR spectra of adjacent LC fractions that received LRMS analysis were compared to the spectrum of the fraction under consideration. (2) The fraction under consideration was matched with the most similar adjacent fraction. (3) The assignment of category/compound weight distribution of the fraction under consideration was made in the same manner as above (using LRMS data). These procedures were repeated for each LC fraction, then the MEG category weights were totalled across fractions and entered as sample totals in the Fortran format		
10,19	ANION ANALYSIS (in various units)	All results converted to weight % and entered	=	M = $^-$ E = $^=$ CLM, FM, SO4E, NO3M, NO2M, CO3E, SE
10	LC GRAVIMETRIC (in µg/g weights in mg)	Entered as reported	=	LC1-LC7
19	LC GRAVIMETRIC (in µg/g weights per fraction)	All results converted to µg/g (conversion factors supplied by EPA Project Officer, Max Samfield)	=	LC1-LC7
10	GC7-GC13 (in µg/g)	Entered as reported	=	GC7-GC13
6,10,19	Hg by AA, reported in various units	All results converted to µg/g	=	HGAA
10,19	Sb by AA, As by AA	All results converted to µg/g	=	SBAA, ASAA
10,19	AQUEOUS ANALYSIS of liquid samples	Entered as reported	=	PH, ACIDTY, ALKNTY, BOD, COD, DO, CONDTY, DISSOL, SUSSOL, CRM, LNSO3E,* H2S, ORGNCS, LNNH3*, LNCNM,* SCNM

(continued)

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[*] In showing an element or compound abbreviation, the initial letters "LN" indicate that a logarithmic transformation has been performed on the data. For ease of identification, "LN" is omitted from the abbreviation after this table.

[†] For a given element/compound abbreviation, a final letter "M" shows a negative charge; "E", two negative charges; and P, a positive charge.

TABLE 10 (continued)

Study	Original results	Quantification	Computer-coded final results
6,10,19	AMES—number of revertant colonies formed relative to dose	The largest ratio of revertants to control colonies (with and without activation) was entered for each strain tested	TA 1535M, TA 1535P, TA 1537M, TA 1537P, TA 98M, TA 98P, TA 100M, TA 100P, TA 1538M, TA 1538P
6,10,19	AMES	Litton* Quantification, using the following parameters:	AMES 2
	RAM	– ATP measurement	RAM
	WI-38	– ATP measurement	WI-38
	CHO	– Mean % survival (viability)	CHO
	RAT	– Lethality	RODENT
	FW algal	– Inhibition of growth	FW AGL
	Grass Shrimp	– Lethality	GRSSHP
	FW fish	– Lethality	FW FSH
	Daphnia	– Lethality (immobility)	DAPNA

*See Table 8 for a detailed description of this method.

SECTION 4

DATA ANALYSIS AND INTERPRETATION

Many approaches were instituted in an effort to analyze the data population and generate an accurate, detailed interpretation. This section will detail the approaches, present results of each approach, and define decision criteria that were used to interpret the results.

The approaches to data analysis are:

1. Basic summary statistics on each sample parameter including maximum values, minimum values, mean, standard deviation, and the number of values in each data set (e.g., total number of fluoride determinations, total number of algal tests).
2. Linear (Pearson) and rank (Spearman) correlation analyses of chemical v. biological parameters and biological v. biological parameters. Correlations were determined for the entire data population (all four studies), as well as for each individual study, and on liquid and solid samples.
3. Scatter plot analysis.
4. Stepwise regression to ascertain antagonistic and/or synergistic effects.
5. Probit analysis of RAM data to linearize the dose-response relationship of such data.
6. Analysis using MEG/MATE values, SAM/IA, and Source Severity models.
7. Description of concurrent cooperative work by Battelle-Columbus Laboratories in evaluating these data using a pattern recognition program, and further statistical analysis by Don Lewis of EPA/RTP.
8. Analysis of engineering data from the FBC process (study 10).
9. Original results compared to the Litton quantification scheme.
10. Correlations among Ames/Salmonella strains.
11. Comparison of schemes for ranking samples.

To show the limited nature of the data being examined, a representative scatter plot of typical values is provided in Figure 4; these data show a "good" correlation (correlation ≥ 0.50 with a significance factor <0.05) according to the study's decision criteria.

4.1 SUMMARY STATISTICS

It was determined from examining the summary statistics that there are much greater ranges of chemical concentration values and biological response values in the FBC study (study 10), the coal gasification study (study 06), and the SASS evaluation (study 15) than in the textile study (study 19). This may be due to the nature of the samples. The textile study data set consisted of only treated aqueous effluents from textile plants, while the other three studies' data sets consisted of various aqueous and organic liquid and solid samples.

4.2 CORRELATION ANALYSIS

The correlation studies were executed utilizing the statistical analysis system (SAS),[12] a packaged computer program. Data from the 51 sample sets were entered and sorted by study (06, 10, etc.), by sample (cyclone dust, tar, etc.), by analytical test (Ames, SSMS, etc.), and by chemical (Zn, $CO_3^=$, etc.); the group of sample data sets presented in Appendix A was the first output. The basic summary statistics were calculated for each parameter as discussed in the previous section.

To determine the degree of association between pairs of variables, the correlation coefficients were calculated. Two types of correlations were computed: the linear (Pearson Product-Moment) correlation and the rank (Spearman) correlation. The linear correlation is used in cases where normality and linearity can be assumed. The rank correlation makes no assumptions regarding normality or linearity, and seems to be more appropriate for this data set; therefore only rank correlations are discussed.

4.2.1 Rank (Spearman) Correlation (r_s)

The Spearman correlation is based on rankings and, in contrast to the linear correlation, makes no assumptions about normality or linearity. Thus, in the present case where many of the data were discrete (e.g., the Ames test results) or highly skewed (e.g., many of the chemical test

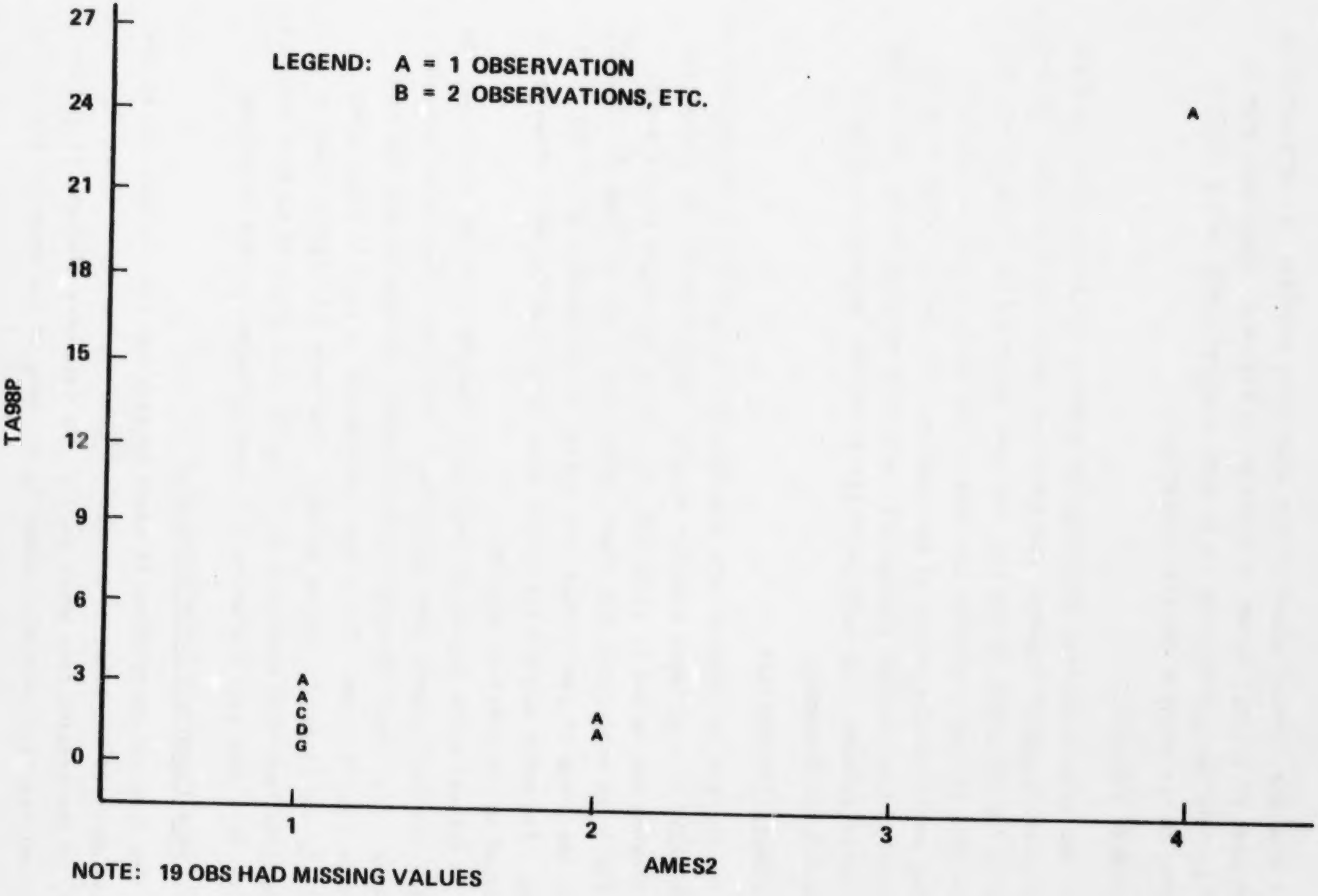


Figure 4. Plot of TA98P vs. AMES2.

results), it appears that this correlation is more appropriate than the Pearson correlation. To compute this correlation, complete the following steps:

1. Rank the observations of the X variable from 1 to N.
2. Rank the observations of the Y variable from 1 to N.
3. List the corresponding N observations for X and Y and beside each observation give the observation's rank.
4. Determine the value of d_i for each observation by subtracting the Y rank from the X rank. Square this value to determine each observation's d_i^2.
5. Sum the d_i^2's for the N observations to determine $\sum d_i^2$.
6. Compute the rank correlation by the formula

$$r_s = 1 - \frac{6 \sum_{i=1}^{N} d_i^2}{N(N^2-1)} \quad . \tag{1}$$

The above computations can be demonstrated by using the data in Table 11.

Note in Table 12 that when two observations are tied, each receives the average of the two ranks that would have been assigned had no ties occurred (e.g., for X = 0 in Table 11, the average of the ranks is 1.5 in Table 12).

From the computations in Table 12, r_s is computed by equation (1) as

$$r_s = 1 - \frac{6(109.50)}{12(144-1)} = 0.617.$$

To test whether r_s is significantly different from zero, a two-tailed test of significance can be performed. The test of significance is based on the Student's-t distribution with N-2 degrees of freedom. The statistic is computed as follows:

$$t_{N-2} = r_s \left[\frac{N-2}{1-r_s^2}\right]^{\frac{1}{2}} \quad . \tag{2}$$

The value computed by equation (2) is compared with t-tables for N-2 degrees of freedom. For our example data,

$$t_{10} = 0.62 \left[\frac{12-2}{1-(0.62)^2}\right]^{\frac{1}{2}} = 2.50,$$

TABLE 11. EXAMPLE DATA FOR RANK CORRELATION

Observation	X	Y	Observation	X	Y
1	0	42	7	5	86
2	0	46	8	6	56
3	1	39	9	7	62
4	1	37	10	8	92
5	3	65	11	8	54
6	4	88	12	12	81

TABLE 12. COMPUTATIONS FOR RANK CORRELATION

	Rank			
Observations	X	Y	d_i	d_i^2
1	1.5	3	−1.5	2.25
2	1.5	4	−2.5	6.25
3	3.5	2	1.5	2.25
4	3.5	1	2.5	6.25
5	5	8	−3.0	9.00
6	6	11	−5.0	25.00
7	7	10	−3.0	9.00
8	8	6	2.0	4.00
9	9	7	2.0	4.00
10	10.5	12	−1.5	2.25
11	10.5	5	−5.5	30.25
12	12	9	3.0	9.00
				$\Sigma d_i^2 = 109.50$

TABLE 13. "GOOD" RANK CORRELATIONS IN STUDY 15

	RAM		RAM
Mo	+	Be	+
V	+	Mn	−

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for each chemical element.

+ = Positive correlation.

− = Negative correlation.

which for a two-tailed test is significantly different from zero at the 0.05 level of significance.

In summary, if the absolute value of the correlation coefficient is close to 1, then a good correlation is said to exist. If examination of the scatter plot (graph of all data pairs used in a correlation) shows the data spread along the correlation curve and eliminates the presence of a single high value influencing a correlation, the statement of association is further validated. Well-defined dose-response nonlinear curves, as shown by data plots, are also important to note. The evaluation of scatter plots is discussed in the next section of this chapter.

In the remaining analyses, no assumptions of the presence or absence of a linear relationship between chemical and biological results were made; the effort was directed at identifying trends or relationships. For this purpose, data from the four studies were analyzed collectively, each study was analyzed independently of the others, and then liquid and solid samples were analyzed separately.

Correlations were performed on the following data sets:

1. Original investigator's biotest results v. original investigator's biotest results to determine interrelationships among the biotests.
2. Original biotest results v. chemical results to determine the existence of relationships between chemical concentrations and response in biological systems.
3. Ames test bacterial strains v. Ames test bacterial strains to determine interrelationships among the test strains (e.g., TA98 v. TA1538).
4. Biotest results quantified by Litton v. chemical results.
5. Biotest results quantified by Litton v. originally reported biotest results.

The output of the SAS correlation programs showed the correlation coefficient, a probability factor, and the size of the correlation data set. For example, the rank correlation for parameters RAM1000 v. Uranium concentration across all four studies generated the following results:

0.42432
0.1305
14

The correlation coefficient of 0.42432 is low so a significant rank correlation would not be expected. In addition, the probability factor of 0.1305 indicates a significant probability exists that the correlation could be due to chance (i.e., only when the probability factor is smaller than 0.05 would the correlation be considered significantly different from zero at the 0.05 level). The number of data pairs is 14; that is, 14 samples contained data on both uranium concentration and rabbit alveolar macrophage response.

Decision criteria were established to reduce the number of correlations considered for more detailed analysis. The decision made was to tabulate all paired data sets that had a rank correlation coefficient greater than or equal to 0.50 plus a significance factor less than 0.05. All linear and rank correlations meeting these criteria were noted as "possible" or "good" relationships and are reported in Appendix C. Since rank correlations are considered more appropriate for this data set, the following section discusses each group of "good" rank correlations. The discussion of results in each study or grouping is organized to include the following:

Chemistry v. Biology (Ecology-related)
Chemistry v. Biology (Health-related)
Biology (Ecology) v. Biology (Ecology)
Biology (Ecology) v. Biology (Health)
Biology (Health) v. Biology (Health)

A positive correlation implies that the value of one parameter (biological response, chemical concentration) increases as the value of the other parameter increases. A negative correlation implies that one parameter decreases as the other increases. Because LD_{50}, LC_{50}, EC_{50}, and EC_{20} values are expressed as percent sample concentration in this data set, a negative correlation coefficient for these parameters implies a positive relationship; that is, $LD_{50} \propto 1/\text{intensity of biological response}$.

4.2.2 Study 06--Coal Gasifier

There were only four samples in the data set. This sample size is too small to use in drawing conclusions, so no correlations are given.

4.2.3 Study 10--Fluidized-Bed Combustor

There were only six samples in the data set. This sample size is too small to use in drawing conclusions, so no correlations are given.

4.2.4 Study 15--SASS Train Evaluation, Various Industries

Sixteen sample were in this group. Only the RAM test results are in the data set; these "good" rank correlations were shown: RAM cell viability was positively correlated with Mo, V, and Be, and negatively correlated with Mn.

Table 13, page 40, summarizes the "good" rank correlations in Study 15.

4.2.5 Study 19--Textile Plants' Effluents

There were 15 samples in this group. This study had the most complete data set and many "good" rank correlations were found:

- The RAM test was positively correlated with Pb, W, Hf, Yb, Tm, Dy, Tb, Eu, Sm, Nd, Cd, Ag, Nb, Zr, Sr, Rb, Ni, V, NO_2^-, pH, and NO_3^-.
- The RAT parameter, which considered behavioral and physiological effects, was positively correlated with Pb, Ta, Yb, Er, Zr, and Fe, and negatively correlated with MEG1, LC4, and LC5.
- The freshwater algal test was positively correlated with Pb, Sm, Ce, Cr, and S, and negatively correlated with MEG1.
- The saltwater algal test was positively correlated with Ce, Zr, and V.
- The freshwater fish test was positively correlated with U, Pb, Dy, Sm, Ce, Sn, Ag, Zr, Y, Sr, Rb, Ni, V, Li, NO_3^-, and total organics, and negatively correlated with Cl, LC6, and As.
- The *Daphnia* test was positively correlated with Ce, La, Zr, Mn, Ca, and NO_3^-.
- The saltwater fish test was positively correlated with U, Th, Pb, Tl, Hf, Lu, Yb, Tm, Er, Dy, Gd, Eu, Cd, Ag, Zr, Y, Sr, Rb, Ga, Sc, Ca, Si, Be, As, and conductivity, and negatively correlated with MEG8 and LC6.

- The grass shrimp test was positively correlated with U, Th, Bi, Pb, W, Hf, Lu, Yb, Tm, Er, Dy, Gd, Eu, Nd, Cd, Ag, Y, Sr, Rb, Ni, Sc, Ca, Si, Be, and conductivity, and negatively correlated with MEG8 and LC6.
- Ames strain TA1535 (no S-9) and Ames strain TA98 (no S-9) were positively correlated with CHO.
- Ames strain TA98 (with S-9) was positively correlated with RAM cell viability.
- The freshwater fish test was positively correlated with the saltwater algal test, the *Daphnia* test, the saltwater fish test, and the grass shrimp test.
- The saltwater fish test was positively correlated with the *Daphnia* test, RAM cell viability, and RAM ATP level.
- The grass shrimp test was positively correlated with the *Daphnia* test and the saltwater fish test.

Table 14 summarizes "good" correlations for Study 19.

4.2.6 All Studies Grouped Together

All data (51 samples) from studies 06, 10, 15, and 19 considered together give these "good" rank correlation.

- The RAM test was positively correlated with Cd, Br, S, MEG1, MEG18, MEG21, MEG23, MEG25, NO_3^-, NO_2^-, LC2, LC8, and Cl_2, and negatively correlated with Ce, Ga, Fe, V, Ti, Cu, Si, Mg, Be, and Hg.
- The Ames test was positively correlated with Bi, Pb, Ga, MEG2, MEG15, LC1, LC2, LC3, Hg, and As.
- The RAT test was positively correlated with Pb, Fe, and MEG1.
- The freshwater algal test was positively correlated with Ce, La, Ba, Sr, Rb, As, Mn, Ti, Ca, K, S, Mg, F, and $SO_4^=$.
- The saltwater algal test was positively correlated with Ce, Zr, and $SO_4^=$.
- The freshwater fish test was positively correlated with Pb, Li, and total organics, and negatively correlated with MEG15.
- The *Daphnia* test was positively correlated with Ca.

TABLE 14. "GOOD" RANK CORRELATIONS IN STUDY 19

	RAM	CHO	RAT	FW ALGAL	SW ALGAL	FW FISH	DAPHNIA	SW FISH	GRASS SHRIMP	WI-38	AMES
U						+		+	+		
Th								+	+		
Bi									+		
Pb	+		+	+		+		+	+		
W	+							+	+		
Ta			+								
Hf	+							+	+		
Lu								+	+		
Yb	+		+					+	+		
Tm	+							+	+		
Er			+					+	+		
Dy	+					+		+	+		
Tb	+										
Gd								+	+		
Eu	+							+	+		
Sm	+			+		+					
Nd	+								+		
Ce				+	+	+	+				
La							+				
Sn						+					
Cd	+							+	+		
Ag	+					+		+	+		
Nb	+										
Zr	+		+		+	+	+	+			
Y						+		+	+		
Sr	+					+		+	+		
Rb	+					+		+	+		
As						−					
Ga								+			
Ni	+					+			+		
Fe			+								
Mn							+				
Cr				+							
V	+				+	+					
Sc								+	+		
Ca							+	+	+		
Cl						−					
S				+							
Si								+	+		
Be								+	+		
Li						+					

See notes at end of table. (continued)

TABLE 14. (continued)

	RAM	CHO	RAT	FW ALGAL	SW ALGAL	FW FISH	DAPHNIA	SW FISH	GRASS SHRIMP	WI-38	AMES
MEG1			—	—							
MEG8								—	—		
NO_3^-	+					+	+				
NO_2^-						+					
LC4			—								
LC5			—								
LC6						—		—	—		
As-AA								+			
pH	+										
Conductivity								+	+		
Cr^{++}	+										
Total organics						+					

+ = Positive correlation.

— = Negative correlation.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.

- The saltwater fish test was negatively correlated with MEG15 and LC6 and positively correlated with conductivity.
- The grass shrimp test was positively correlated with U, W, Cd, Ag, Sr, Rb, Sc, Ca, Si, and conductivity, and negatively correlated with MEG15 and LC6.
- The RAT test was positively correlated with Sr, Rb, Sc, and LC3, and negatively correlated with MEG3, MEG5, and DO.
- The saltwater algal test was positively correlated with the freshwater algal test, the freshwater fish test, and the saltwater fish test.
- The freshwater algal test was positively correlated with RAM ATP and WI-38.
- The freshwater fish test was positively correlated with grass shrimp and RAM ATP.
- The Daphnia test was positively correlated with the freshwater fish test, saltwater fish test, and grass shrimp test.
- The saltwater fish test was positively correlated with the freshwater fish test, grass shrimp test, RAM ATP, and RAM cell viability.
- The grass shrimp test was positively correlated with RAM ATP and RAM cell viability.
- The RAM test was positively correlated with Ames strain TA98 (with S-9), TA1538 (with S-9), and WI-38.
- The CHO test was positively correlated with Ames strains TA1535 (no S-9) and TA98 (no S-9).
- The RAT test was positively correlated with Ames strain TA1535 (with S-9).

Table 15 summarizes the significant correlations found in the data set of all studies combined.

4.2.7 Liquids

There were 15 liquid samples from studies 06, 10, and 19. They showed these "good" rank correlations:

- The RAM test was positively correlated with W, Cd, Ag, Rb, Br, Sc, Si, MEG1, $SO_4^=$, pH, and Cr^{++}, and negatively corre-

TABLE 15. "GOOD" RANK CORRELATIONS FROM ALL STUDIES COMBINED

	RAM	CHO	RAT	FW ALGAL	SW ALGAL	FW FISH	DAPHNIA	SW FISH	GRASS SHRIMP	WI-38	AMES
U									+		
Bi											+
Pb			+			+					+
W									+		
Ce	−			+	+						
La				+							
Ba				+							
Cd	+								+		
Ag									+		
Zr					+						
Sr			+	+					+		
Rb			+	+					+		
Br	+										
As				+							
Ga	−										+
Fe	−		+								
Mn				+							
V	−										
Ti	−			+							
Sc			+						+		
Ca	−			+			+		+		
K				+							
S	+			+							
Si	−								+		
Mg	−			+							
F				+							
Li						+					
Be	−										
MEG1	+		−								
MEG2											+
MEG3			−								
MEG5			−								
MEG15						−		−	−		+
MEG18	+										
MEG21	+										
MEG23	+										
MEG25	+										
$SO_4^=$				+	+						
NO_3^-	+										
NO_2^-	−										

See notes at end of table.

(continued)

TABLE 15. (continued)

	RAM	CHO	RAT	FW ALGAL	SW ALGAL	FW FISH	DAPHNIA	SW FISH	GRASS SHRIMP	WI-38	AMES
LC1											+
LC2	+										+
LC3			+								+
LC6								—	—		
LC8	+										
Hg-AA	—										+
As-AA											+
pH	+										
DO			—								
Conductivity								+	+		
Organics						+					

+ = Positvie correlation.

— = Negative correlation.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.

lated with U, Th, Bi, Pb, Tl, Au, Pt, Ir, Os, Hf, Lu, Yb, Tm, Er, Ho, Dy, Tb, Gd, Eu, Sm, Nd, Pr, Te, Pd, Rh, Ru, Mo, Ge, Ga, Ni, Fe, V, Na, Be. and Hg.

- The RAT test was positively correlated with Pb, Ta, Hf, Yb, Er, Mo, Fe, Cs, Rb, and Na, and negatively correlated with MEG1, MEG18, LC5, and DO.
- The freshwater algal test was positively correlated with W, Ce, La, Bu, Cs, Ag, Nb, Lr, Y, Sr, Rb, As, Mn, Ti, Ca, K, S, Mg, F, $SO_4^=$, and NO_3^-.
- The freshwater fish test was positively correlated with Pb, Li, and total organics, and negatively correlated with MEG15.
- The Daphnia test was positively correlated with Ce.
- The saltwater fish test was positively correlated with MEG15 and conductivity, and negatively correlated with LC6.
- The grass shrimp test was positively correlated with U, W, Cd, Ag, Sr, Rb, Sc, Si, and conductivity, and negatively correlated with MEG15 and LC6.
- The freshwater algal test was positively correlated with RAM ATP and WI-38.
- The saltwater algal test was positively correlated with freshwater algal test and freshwater fish test.
- The freshwater fish test was positively correlated with the saltwater algal test, grass shrimp test, and RAM ATP.
- The Daphnia test was positively correlated with the freshwater fish test.
- The saltwater fish test was positively correlated with saltwater algal test, freshwater fish test, Daphnia test, grass shrimp test, RAM cell viability, and RAM ATP.
- The grass shrimp test was positively correlated with the freshwater fish test, Daphnia test, RAM ATP, and RAM cell viability.
- The RAM test was positively correlated with WI-38, RAT, and Ames strains TA1537 (no S-9) and TA98 (with S-9).
- The CHO test was positively correlated with Ames strains TA1535 (no S-9) and TA98 (no S-9).

Table 16 shows the "good" correlations on the liquid samples.

TABLE 16. "GOOD" RANK CORRELATIONS IN LIQUID SAMPLES

	RAM	CHO	RAT	FW ALGAL	SW ALGAL	FW FISH	DAPHNIA	SW FISH	GRASS SHRIMP	WI-38	AMES
U	−								+		
Th	−										
Bi	−										
Pb	−		+			+					
Tl	−										
Au	−										
Pt	−										
Ir	−										
Os	−										
W	+			+					+		
Ta			+								
Hf	−		+								
Lu	−										
Yb	−		+								
Tm	−										
Er	−		+								
Ho	−										
Dy	−										
Tb	−										
Gd	−										
Eu	−										
Sm	−										
Nd	−										
Pr	−										
Ce				+							
La				+							
Ba				+							
Cs			+								
Te	−										
Cd	+								+		
Ag	+								+		
Pd	−										
Rh	−										
Ru	−										
Mo	−		+								
Zr				+							
Y				+							
Sr				+					+		
Rb	+		+	+					+		
Br	+										
As				+							

See notes at end of table.

(continued)

TABLE 16. (continued)

	RAM	CHO	RAT	FW ALGAL	SW ALGAL	FW FISH	DAPHNIA	SW FISH	GRASS SHRIMP	WI-38	AMES
Ge	—										
Ga	—										
Ni	—										
Fe	—		+								
Mn				+							
V	—										
Ti				+							
Sc	+								+		
Ca				+							
K				+							
S				+							
Si	+								+		
Mg				+							
Na	—		+								
F				+							
Be	—										
Li						+					
MEG1	+		—								
MEG15						—		+	—		
MEG18			—								
$SO_4^=$				+							
NO_3^-	+			+							
LC5			—								
LC6								—	—		
Hg-AA	—										
pH	+										
DO			—								
Conductivity								+	+		
Cr^{++}	+										
Organics						+					

+ = Positive correlation.

— = Negative correlation.

Note: The transformation x = log(c + 1), where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.

4.2.8 Solids

There were nine samples from studies 06, 10, and 19 used in the correlation matrix; correlations obtained were:

- The Ames test was positively correlated with Bi, I, Pb, F, MEG1, MEG2, MEG15, MEG21, MEG25, LC2, and LC3, and negatively correlated with Cl^-.
- The RAM test was positively correlated with Bi, I, MEG1, MEG2, MEG15, MEG21, MEG25, LC1, LC2, LC3, and LC8, and negatively correlated with P.
- The Ames test was positively correlated with RAM.

Table 17 summarizes the correlations for solids data.

4.2.9 Summary Correlations

It is readily apparent that there were many potential or possible relationships based on the data from these four studies. It is also apparent that some of these "good" correlations are due to the small number of data points, because the relative number of "good" correlations tends to decrease when the number of data pairs used in calculating the correlation coefficient increases. More data, as suggested in the last section of this document, would produce a data analysis with greater statistical reliability and validity.

As noted previously, both rank and linear correlations were examined for studies 06, 10, 15, 19, all studies combined, all liquid samples combined, and all solid samples combined. Relationships noted below are cases where the study groupings show at least two "good" correlations including at least one "good" rank correlation. With these qualifiers in mind, the following trends were observed from this analysis of the environmental assessment data:

1. Pb was correlated with the greatest number of bioassays, followed by Rb. Pb concentration was correlated with seven biological parameters: Ames, RAM, RAT, freshwater algal, freshwater and saltwater fish, and grass shrimp. Rb was correlated with six biological parameters: RAM, RAT, freshwater algal, freshwater and saltwater fish, and grass shrimp.

TABLE 17. "GOOD" RANK CORRELATIONS IN SOLIDS SAMPLES*

	RAM	AMES		RAM	AMES
Bi	+	+	MEG15	+	
Pb		+	MEG21	+	+
I	+	+	MEG23	+	
Cl		−	MEG25	+	+
P	−		LC1	+	
F		+	LC2	+	+
MEG1	+	+	LC3	+	+
MEG2	+	+	LC8	+	

+ = Positive correlation.

− = Negative correlation.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.

2. The rabbit alveolar macrophage (RAM) test appeared to be more sensitive for this group of samples, being correlated with 60 chemical parameters, as compared to Daphnia, which was correlated with 1 chemical parameter.

Table 18 summarizes those chemistry v. biology combinations that show at least two "good" correlations, including at least one "good" rank correlation. As previously stated, the correlations had been run on each study individually, on all studies together, on liquid samples, and on solid samples; combinations where the correlation coefficient was greater than 0.50 with a significance level less than 0.05 had been selected as "good".

Table 19 summarizes the biology v. biology combinations that show at least two "good" correlations, including at least one "good" rank correlation. In Table 19, it is of interest to note that all the aquatic animal tests were correlated; that is, all possible combinations involving saltwater fish, freshwater fish, Daphnia, and grass shrimp were interrelated and qualify as "good" correlations. The freshwater algal test was the only ecology-related test that correlated with more than one health-related test, showing possible relationships with the RAM and WI-38 tests. The RAM test (health-related) was correlated with the freshwater and saltwater fish and grass shrimp tests as well as with the freshwater algal test. As expected, the freshwater and saltwater algal tests were highly correlated, as were the RAM and WI-38 cytotoxicity tests.

4.3 SCATTER PLOT ANALYSIS

The criteria for discussion of scatter plots were similar to those used in discussion of "good" correlations. Scatter plots are discussed for cases where a "good" rank correlation for all studies combined was shown supported by a "good" correlation for at least one other grouping.

In discussions of the chemical-biological test combinations, it should be noted that the chemical parameter is considered the independent variable, on the x-axis, and the biological parameter is considered the dependent parameter, on the y-axis.

In examining the scatter plots, several patterns in the data become apparent. However, it must be remembered that the data base is statistically too small, with too few observations and too many missing numbers, for the

TABLE 18. SUMMARY OF CHEMICAL AND BIOLOGICAL TEST COMBINATIONS WHERE STUDY GROUPINGS SHOW AT LEAST TWO "GOOD" CORRELATIONS INCLUDING AT LEAST ONE "GOOD" RANK CORRELATION

	Biological tests									
	Health-Related				Ecology-Related					
Chemical tests	AMES	RAM	RAT	CHO	FW ALGAL	SW ALGAL	FW FISH	SW FISH	DAPHNIA	GRASS SHRIMP
U		X*						X		X
Th	X*	X*						X		X
Bi	X	X*								
Pb	X	X	X		X		X	X		X
Tl	X*	X*								
Au		X*								
Pt		X*								
Ir		X*								
Os		X*								
W	X*	X						X		X
Ta			X*							
Hf	X*	X						X		X
Lu	X*	X*								X
Yb		X	X					X		X
Tm		X						X		X
Er	X*	X*	X							X
Ho	X*	X*								
Dy	X*	X					X	X		X
Tb	X*	X								
Gd	X*	X*								X
Eu	X*	X						X		X
Sm		X								
Nd		X								
Pr	X*	X*								
Ce					X	X				
La					X					
Ba	X*				X					
Cs	X*		X							
I	X*	X*								
Te		X*								
Sn							X			
Cd		X								X
Ag	X*	X								X
Pd		X*								
Rh		X*								
Ru		X*								
Mo		X	X							
Zr		X	X			X	X	X		
Y	X*						X	X		
Sr		X			X		X	X		X
Rb		X	X		X		X	X		X
Br		X								
As	X*				X					
Ge	X*	X*								

(continued)

TABLE 18. (continued)

Chemical tests	Biological tests									
	Health-related				Ecology-related					
	AMES	RAM	RAT	CHO	FW ALGAL	SW ALGAL	FW FISH	SW FISH	*DAPHNIA*	GRASS SHRIMP
Ga	X	X*								
Zn	X*									
Ni	X*	X					X*			
Fe		X	X							
Mn					X					
Cr	X*				X					
V		X								
Ti		X			X					
Sc										X
Ca		X*			X				X	X
K					X					
Cl	X*									
S		X*			X					
Si	X*	X								X
Mg		X			X					
F	X*				X					
Be	X*	X								
Li							X			
MEG1	X*	X	X							
MEG2	X*	X*								
MEG3			X*							
MEG5			X*							
MEG8		X*						X		X
MEG15	X	X*					X*	X*		X*
MEG18		X								
MEG21	X*	X*								
MEG23		X*								
MEG25	X*	X*								
F^-	X*									
$SO_4^=$					X	X				
NO_3^-		X								
NO_2^-		X								
LC1	X	X*								
LC2	X	X								
LC3	X	X*								
LC4			X							
LC5		X*	X							
LC6								X		X
LC8		X*								

(continued)

TABLE 18. (continued)

	Biological tests									
	Health-Related				Ecology-Related					
Chemical tests	AMES	RAM	RAT	CHO	FW ALGAL	SW ALGAL	FW FISH	SW FISH	DAPHNIA	GRASS SHRIMP
Hg-AA	X	X*								
As-AA	X*									
pH		X								
DO			X							
Conductivity								X		X
Cr^{++}		X								
Organics							X			

*"Good" correlation is based on fewer than 10 pairs of numbers.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.

TABLE 19. SUMMARY OF BIOLOGICAL TEST COMBINATIONS WHERE STUDY GROUPINGS SHOW AT LEAST TWO "GOOD" CORRELATIONS, INCLUDING AT LEAST ONE "GOOD" RANK CORRELATION

	Health-Related			Ecology-Related					
	AMES	RAM	WI-38	FW ALGAL	SW ALGAL	FW FISH	SW FISH	DAPHNIA	GRASS SHRIMP
Health-Related									
AMES	–	X*							
RAM	X*	–	X*	X*		X	X		X
WI-38		X*	–	X*					
Ecology-Related									
FW ALGAL		X*	X*	–	X				
SW ALGAL				X	–	X	X		
FW FISH		X			X	–	X	X	X
SW FISH		X			X	X	–	X	X
DAPHNIA						X	X	–	X
GRASS SHRIMP		X				X	X	X	–

*Correlation is based on fewer than 10 pairs of numbers.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^{=}$, NH_3, and CN^-.

results to be considered conclusive. With these qualifiers in mind the following observations are made. Table 20 lists the chemical v. biological test combinations, grouped by the pattern shown in the scatter plot. Table 21 presents patterns shown among the biological parameters.

4.3.1 Chemical-Biological Test Combinations

Thirteen scatter plots of MEG categories v. RAM parameters were graphed. These plots involved MEG1, MEG18, MEG23, and MEG25. The seven plots showing logarithmic curves plotted the MEG values against RAM1000 (rabbit alveolar macrophage), VIABIND (viability index), and ATP. Figure 5 is a typical plot from the data set showing a logarithmic curve.

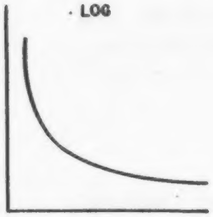
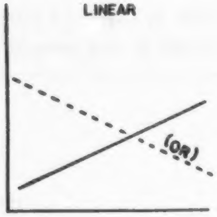
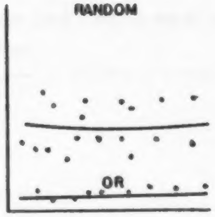
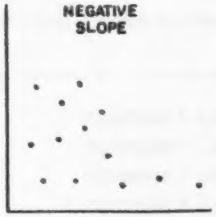
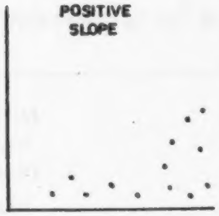
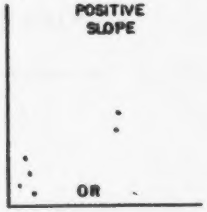
A linear trend is observed in the four plots of MEG values v. PROBVI (viability index probit analysis). A linear trend is also found in the AMES plots for Pb, Bi, and As-AA, as well as the RAM plots of Fe, Si, and Mg values. Figure 6 shows a scatter plot of the linear type.

Scatter diagrams were classified as random observations for many combinations. Approximately one-third of the grass shrimp plots were thought to consist of random observations; chemical parameters involved were U, Si, LC6, and conductivity. Half of the PROBVI plots show a random pattern (Br, S, NO_2^-, NO_3^-), as do a few of the AMES plots (Bi, Ga, Hg-AA). Figure 7 shows a representative random scatter plot.

All freshwater algal samples and almost all saltwater algal samples showed at least a minimal negative slope; that is, the higher chemical values were paired with the lower biological values. The chemical parameters correlating with freshwater algal are Ca, Mn, S, $SO_4^=$, Ba, Sr, Ca, K, Mg, As, and Cd. The chemical parameters related to saltwater algal are Zr and Ce.

In contrast, high values for chemical parameters were sometimes paired with high values for biological parameters, giving a scatter plot with a positive slope. Scatter plots classified thusly include two-thirds of the grass shrimp plots, as well as some AMES2 and RAM (Litton transformation) data. Correlations in this grouping include grass shrimp paired with W, Cd, Ag, Sr, Rb, Ca, Sc, Sr, and Si; AMES2 paired with Pb, Ga, MEG2, MEG10, MEG15, LC1, LC2, and LC3; and RAM paired with MEG1, MEG21, and MEG25.

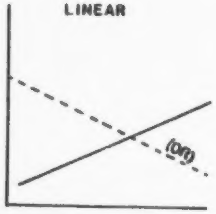
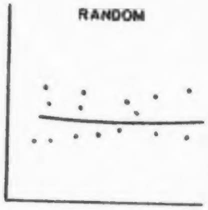
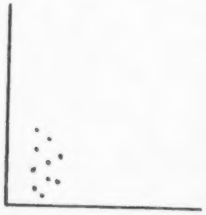
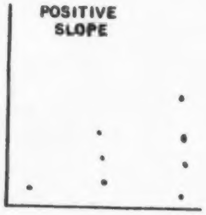
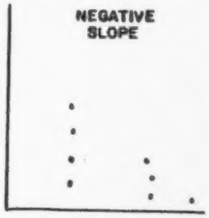
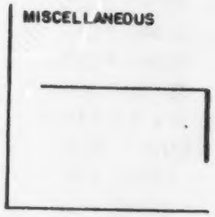
TABLE 20. PATTERNS IN SELECTED SCATTER PLOTS, CHEMICAL TESTS V. BIOASSAYS

LOG	LINEAR	RANDOM	NEGATIVE SLOPE	POSITIVE SLOPE
				 
MEG1 v. RAM1000	ORGNCS v. FWFSH96	$SO_4^{=}$ v. SWALGAL	Ce v. FWALGAL	W v. GSHMP24
*MEG25 v. RAM1000	Cd v. GSHMP48	Li v. FWFSH96	Mn v. FWALGAL	Cd v. GSHMP24
*MEG23 v. VIABIND	pH v. PROBVI	Ca v. DAPH48	S v. FWALGAL	Ag v. GSHMP24
*MEG25 v. VIABIND	*MEG25 v. PROBVI	CONDTY v. SWFSH48	$SO_4^{=}$ v. FWALGAL	Sr v. GSHMP24
MEG1 v. ATP	MEG1 v. PROBVI	LC6 v. SWFSH96	Ba v. FWALGAL	Rb v. GSHMP24
MEG18 v. ATP	*MEG23 v. PROBVI	CONDTY v. GSHMP24	Sr v. FWALGAL	Ca v. GSHMP24
*MEG25 v. ATP	Pb v. AMES1	Si v. GSHMP24	Ca v. FWALGAL	Sc v. GSHMP24
	AsAA v. AMES1	LC6 v. GSHMP24	K v. FWALGAL	W v. GSHMP48
	Pb v. OTHRAT	CONDTY v. GSHMP48	Mg v. FWALGAL	Si v. GSHMP48
	Bi v. AMES2	Sr v. GSHMP48	As v. FWALGAL	Rb v. GSHMP48
	AsAA v. AMES2	LC6 v. GSHMP96	Cd v. PROBVI	Ca v. GSHMP48
	Fe v. RAM	CONDTY v. GSHMP96	MEG1 v. OTHRAT	Ag v. GSHMP48
	Si v. RAM	*MEG5 v. RATWT	Zr v. SWALGAL	Sc v. GSHMP48
	Mg v. RAM	DO v. RATWT	Ce v. SWALGAL	Ag v. GSHMP96
		U v. GRSSHP	V v. RAM	Rb v. GSHMP96
		Pb v. FWFSH		*MEG3 v. RATWT
		Br v. PROBVI		LC2 v. PROBVI
		NO_2^- v. PROBVI		MEG15 v. AMES1
		NO_3^- v. PROBVI		LC2 v. AMES1
		S v. PROBVI		LC3 v. AMES1
		Bi v. AMES1		Pb v. AMES2
		Ga v. AMES1		Ga v. AMES2
		HgAA v. AMES1		*MEG2 v. AMES2
		Fe v. OTHRAT		MEG15 v. AMES2
				LC1 v. AMES2
				LC2 v. AMES2
				LC3 v. AMES2
				MEG1 v. RAM
				*MEG21 v. RAM
				*MEG25 v. RAM

*Correlation is based on fewer than 10 pairs of numbers.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^{=}$, NH_3, and CN^-.

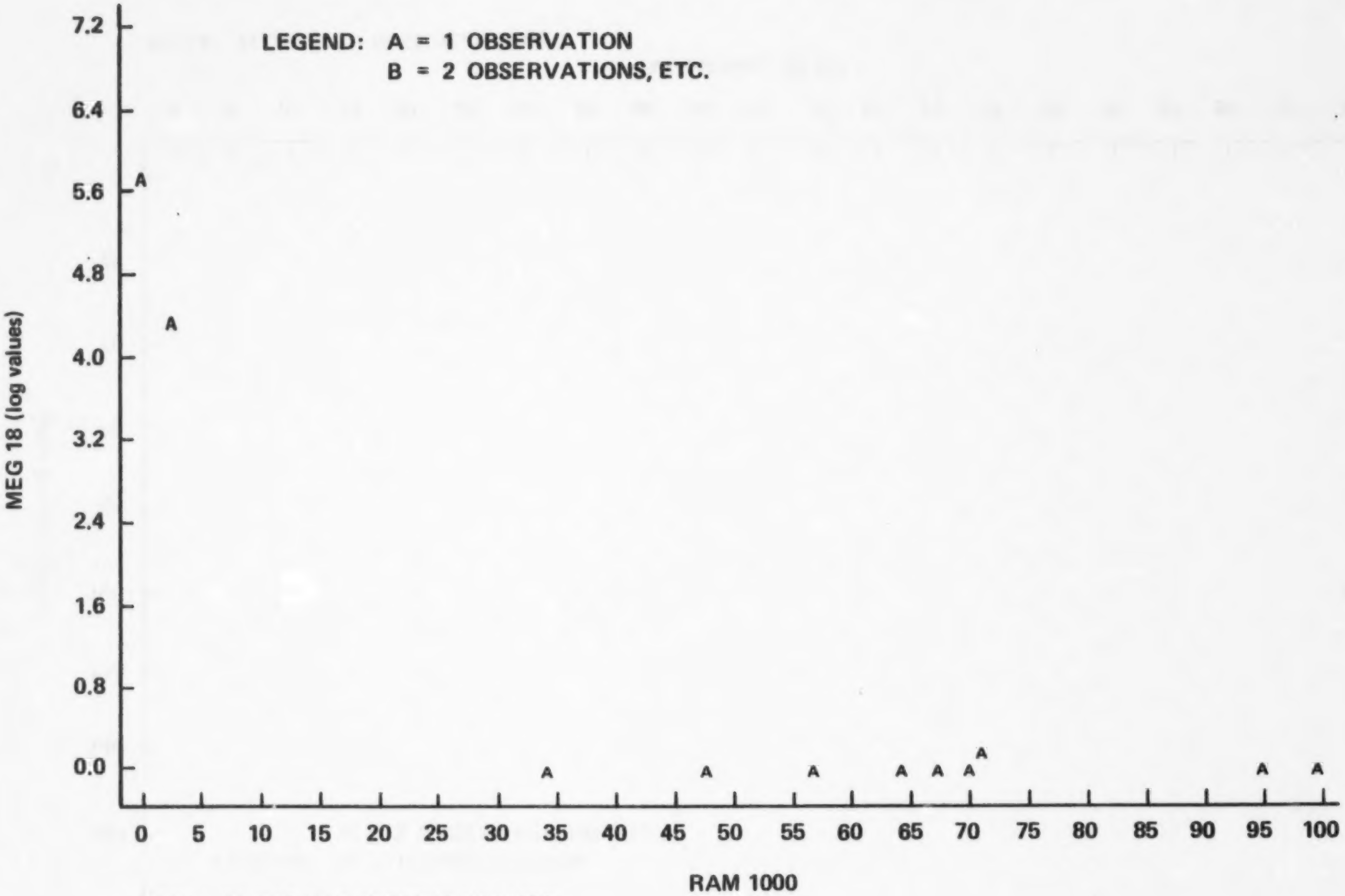
TABLE 21. PATTERNS IN SELECTED SCATTER PLOTS, BIOASSAYS V. BIOASSAYS

LINEAR	RANDOM	POSITIVE SLOPE	NEGATIVE SLOPE	MISCELLANEOUS
	 			
RAM1000 v. ATP RAM1000 v. VIABIND VIABIND v. ATP SWFSH24 v. SWFSH48 SWFSH24 v. SWFSH96 *SWFSH24 v. RAM1000 *SWFSH24 v. VIABIND SWFSH48 v. SWFSH96 *SWFSH48 v. RAM1000 *SWFSH48 v. VIABIND *SWFSH96 v. RAM1000 *SWFSH96 v. VIABIND GSHMP24 v. GSHMP48 *GSHMP24 v. RAM1000 *GSHMP24 v. VIABIND GSHMP48 v. GSHMP96 *GSHMP48 v. RAM1000 *GSHMP48 v. VIABIND GSHMP96 v. GRSSHP *GSHMP96 v. RAM1000 *GSHMP96 v. VIABIND	AMES1 v. TA98P FWFSH96 v. DAPH48 FWFSH96 v. GRSSHP DAPH48 v. GSHMP24 GSHMP48 v. PROBATP GSHMP96 v. PROBATP GRSSHP v. PROBATP RAM1000 v. TA98P VIABIND v. TA98P ATP v. TA1538P AMES1 v. TA1538P PROBVI v. TA98P	AMES1 v. AMES2 AMES1 v. TA100M AMES2 v. TA1538P PROBVI v. RAM PROBATP v. RAM OTHRAT v. TA1535P *FWALGL v. ATP SWALGAL v. FWALGAL SWALGAL v. FWFSH96 SWALGAL v. SWFSH24 SWALGAL v. SWFSH96 FWFSH96 v. SWFSH96 FWFSH96 v. SWFSH48 DAPH48 v. SWFSH96 GSHMP24 v. GSHMP96 GRSSHP v. FWFSH DAPH48 v. SWFSH24	RAM1000 v. PROBATP RAM1000 v. PROBVI RAM1000 v. RAM VIABIND v. PROBVI VIABIND v. RAM ATP v. PROBATP ATP v. RAM *ATP v. WI38 *FWALGL v. WI38 SWALGAL v. FWFSH FWFSH96 v. FWFSH DAPH48 v. FWFSH SWFSH24 v. FWFSH SWFSH48 v. FWFSH SWFSH48 v. PROBVI SWFSH96 v. FWFSH SWFSH96 v. PROBVI GSHMP24 v. FWFSH GSHMP24 v. PROBVI GSHMP24 v. PROBATP GSHMP48 v. FWFSH GSHMP48 v. PROBVI GSHMP96 v. FWFSH GSHMP96 v. PROBVI	SWFSH24 v. GRSSHP SWFSH48 v. GRSSHP SWFSH48 v. PROBATP SWFSH96 v. GRSSHP GSHMP24 v. GRSSHP GSHMP48 v. GRSSHP

---

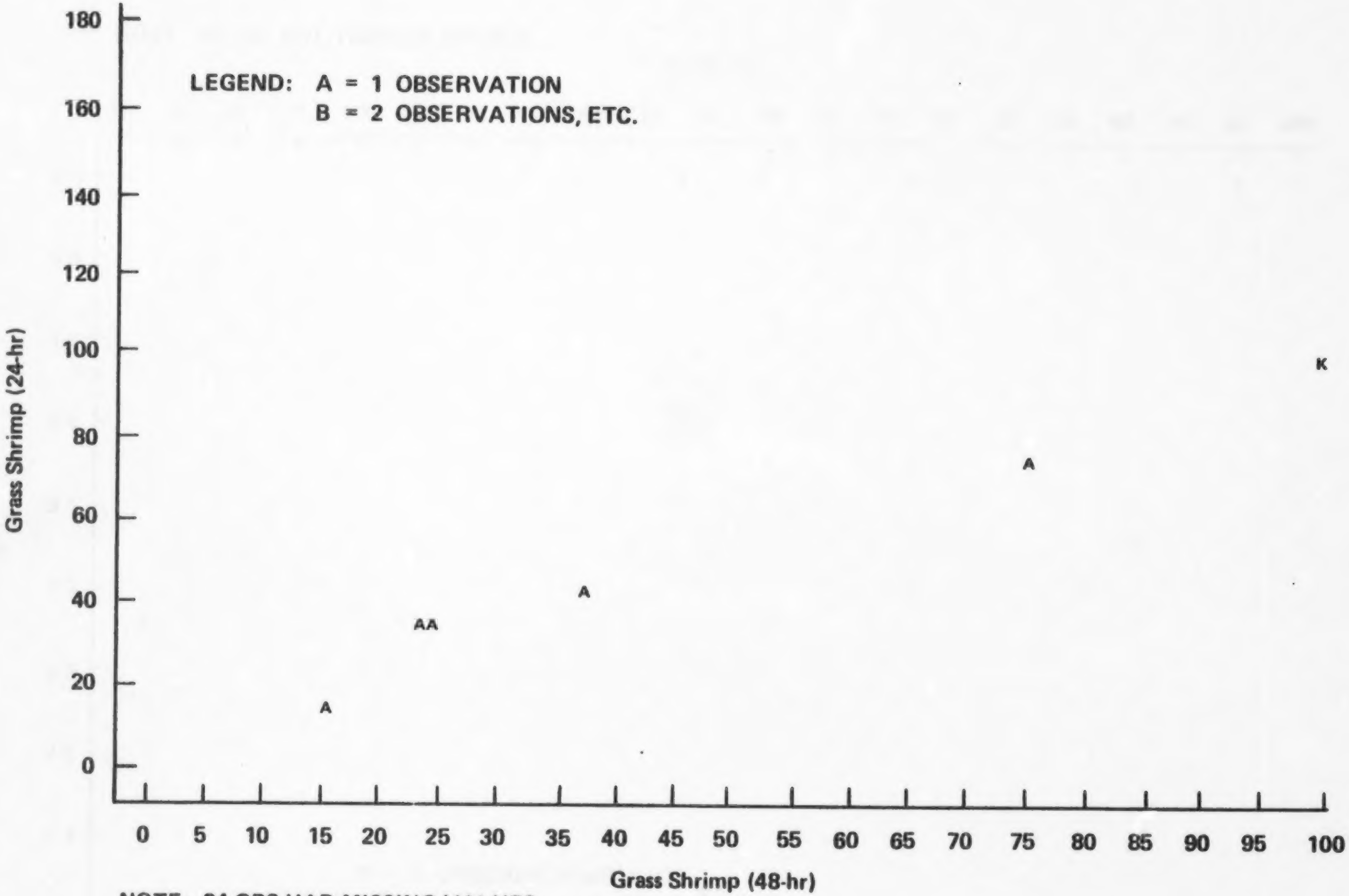
*Correlation is based on fewer than 10 pairs of numbers.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.



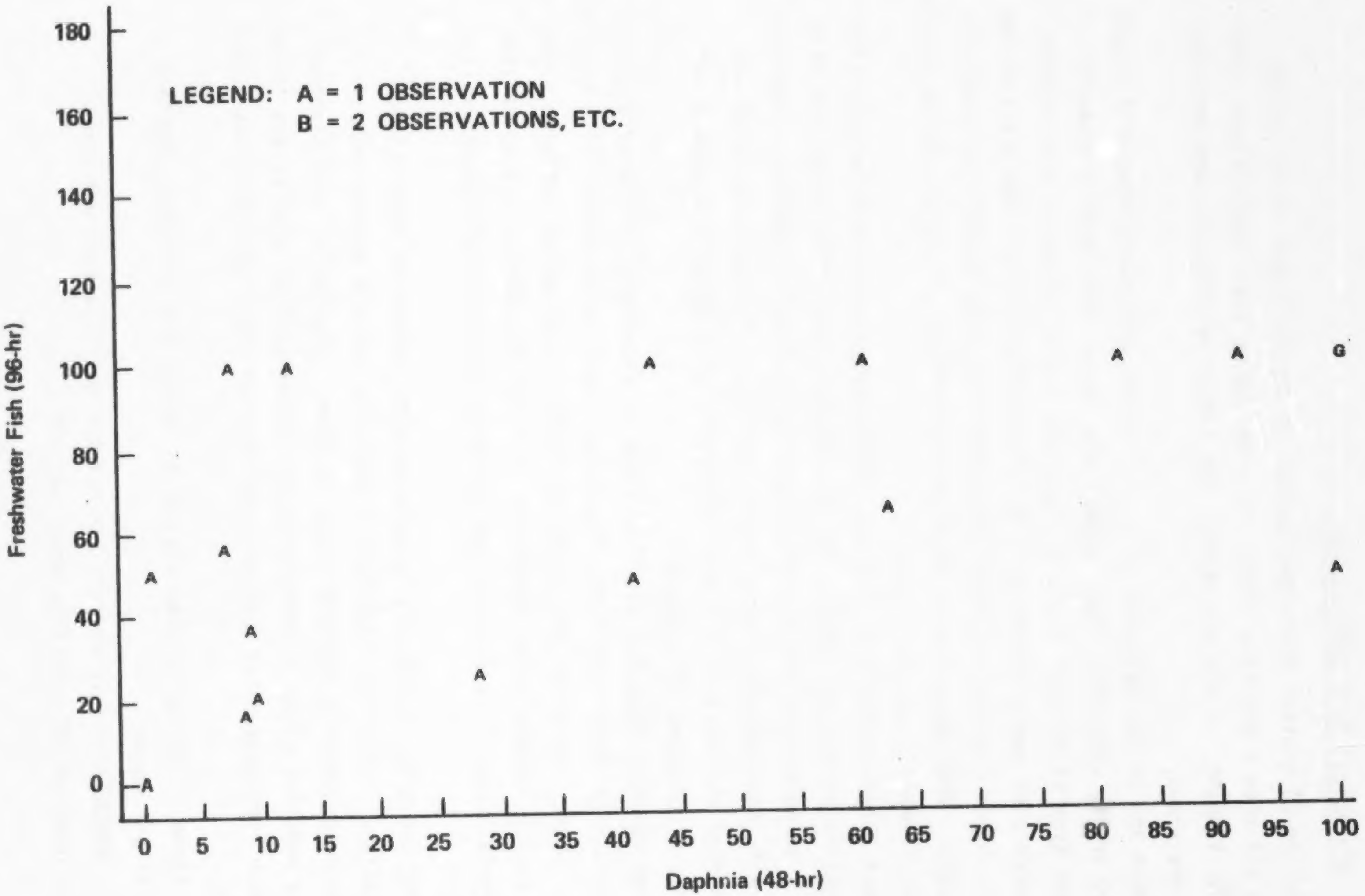
NOTE: 40 OBS HAD MISSING VALUES

Figure 5. Scatter plot showing logarithmic curve pattern.



NOTE: 34 OBS HAD MISSING VALUES

Figure 6. Scatter plot showing linear relationship.



NOTE: 28 OBS HAD MISSING VALUES

Figure 7. Scatter plot showing random distribution.

4.3.2 Biological Test Combinations

Of the 21 scatter plots that appear to depict linear relationships, almost all show a positive slope. As expected by their definitions, when RAM1000, VIABIND, or ATP are paired, the linear relationship and positive slope are shown.

When any of the saltwater fish LC_{50} values were correlated with either RAM1000 or the viability index, a positive linear relationship appeared. The same type of relationship was shown when these saltwater fish studies were correlated among themselves. As with saltwater fish, the grass shrimp studies showed a positive linear relationship to both RAM1000 and viability index data. When measurements were intercorrelated with grass shrimp studies, positive linearity was also shown.

Most correlations involving the (AMES) mutagenicity strains (positive and negative strains of TA1535, TA1537, TA1538, TA98, TA100) show the relationship to be random; these include pairing with AMES1, RAMI000, viability index, ATP, and viability index probit analysis. The correlation of the grass shrimp studies with ATP probit analysis also appears to show a randomly distributed set of numbers.

Some tendency toward a positive slope is shown when saltwater algal is correlated with freshwater fish, freshwater algal, or saltwater fish studies; that is, higher values on the former biological test are paired with higher values on the latter. When freshwater fish (96 hr) studies are correlated with the saltwater fish studies, the tendency toward a positive slope is shown.

When the grass shrimp are correlated with freshwater fish (Litton quantitation), viability index probit analysis, and ATP probit analysis, some tendency toward a negative slope is shown. Similarly, some tendency toward a negative slope is shown when the saltwater fish studies are correlated with freshwater fish (Litton quantitation) and viability index probit analysis.

In terms of health-related biological tests, the following negative tendencies are shown:

1. RAM1000 correlated with RAM (Litton quantitation) and probit analyses of viability index and ATP.

2. Viability index correlated with RAM (Litton quantitation) and probit analysis of viability index (PROBVI).
3. ATP correlated with probit analysis of ATP, and Litton quantitation of RAM and WI-38 human lung fibroblast studies.

Figure 8 shows a scatter plot from the data set with a negative slope.

When the Litton quantitation of the grass shrimp studies is correlated with the (LC_{50}) saltwater fish or (LC_{50}) grass shrimp studies, the plots tend to show a horizontal set of points, followed by a sharp drop (a vertical set of data points). This type of plot shows a high response in the grass shrimp test with varying response levels in the saltwater fish test and lesser response levels in the grass shrimp test at the no-response level in the saltwater fish test. Figure 9 shows the plot of these data.

4.3.3 Summary of "Good" Correlations and Scatter Plots

Table 22 presents a summary of good biological and chemical correlations that also showed "good" scatter plots. "Good" scatter plots are defined herein as those showing linear or logarithmic patterns. Table 22 is in the same format as Table 18 but qualifies the mathematically "good" correlations in Table 18 by listing only those pairings that showed a good mathematical correlation plus a scatter plot that was subjectively evaluated as being "good" (and eliminates those without "good" rank correlations for all studies combined). Thus, Table 22 presents a summary of pairings that were qualified as possibly valid by the screening processes discussed in this section. Eleven of the thirteen combinations showing "good" correlations and scatter plots involved health-related biological tests. Seven of these combinations involved RAM parameters. The chemical parameters involved are Fe, Si, Mg, MEG1, MEG23, MEG25, and pH. AMES parameters were in three of the combinations; the chemical parameters correlated were Bo, Pb, and As-AA. The RAT, freshwater fish, and grass shrimp tests were each combined with one chemical test (Pb, total organics, and Cd, respectively).

Pb was the only chemical test correlated with more than one biological test. As noted above, combinations were Pb v. AMES and Pb v. RAT.

Table 23 presents a similarly qualified summary of "good" correlations and scatter plots for selected correlations involving bioassay v. bioassay. The only health-related parameter involved is the set of RAM parameters; it

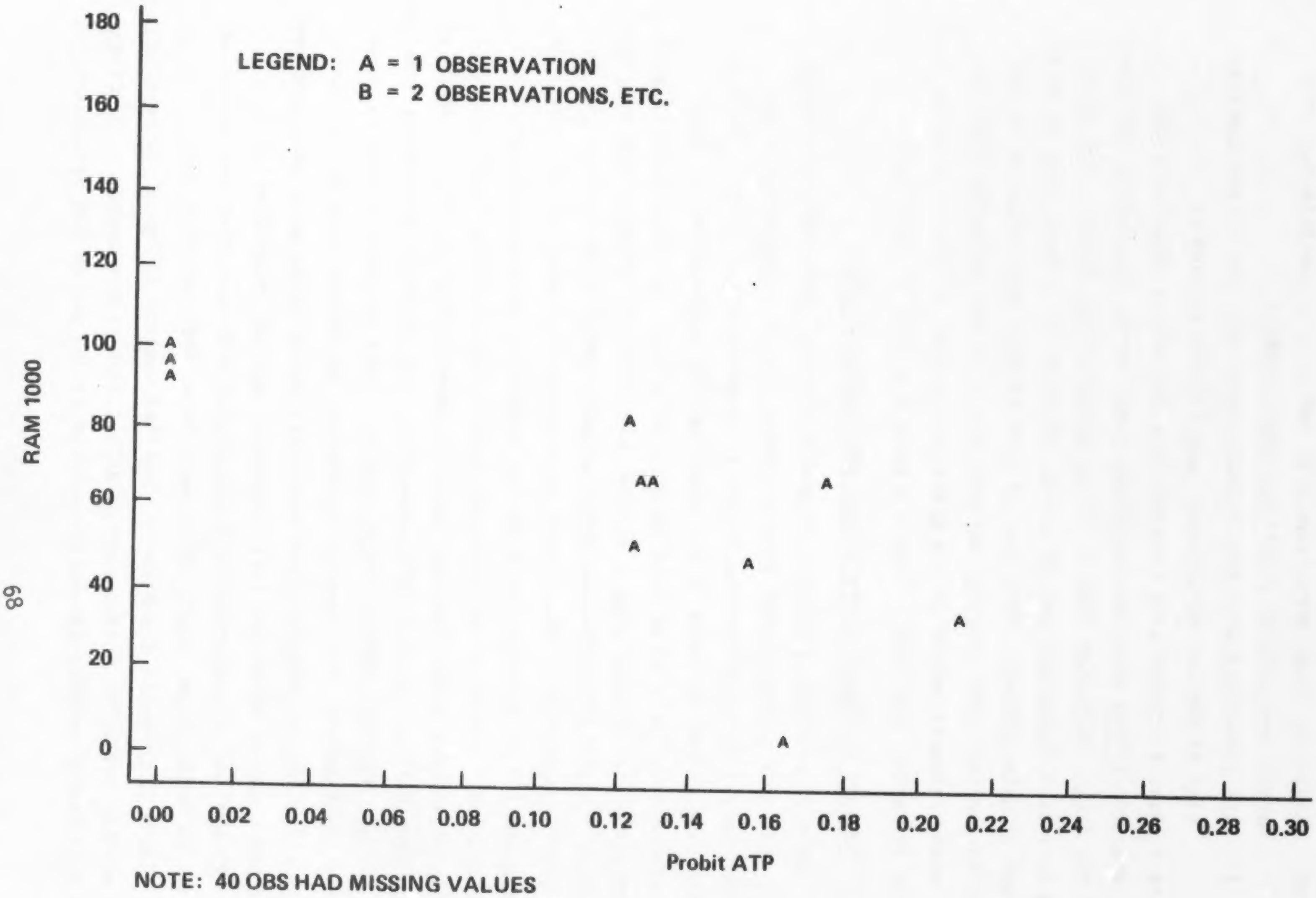
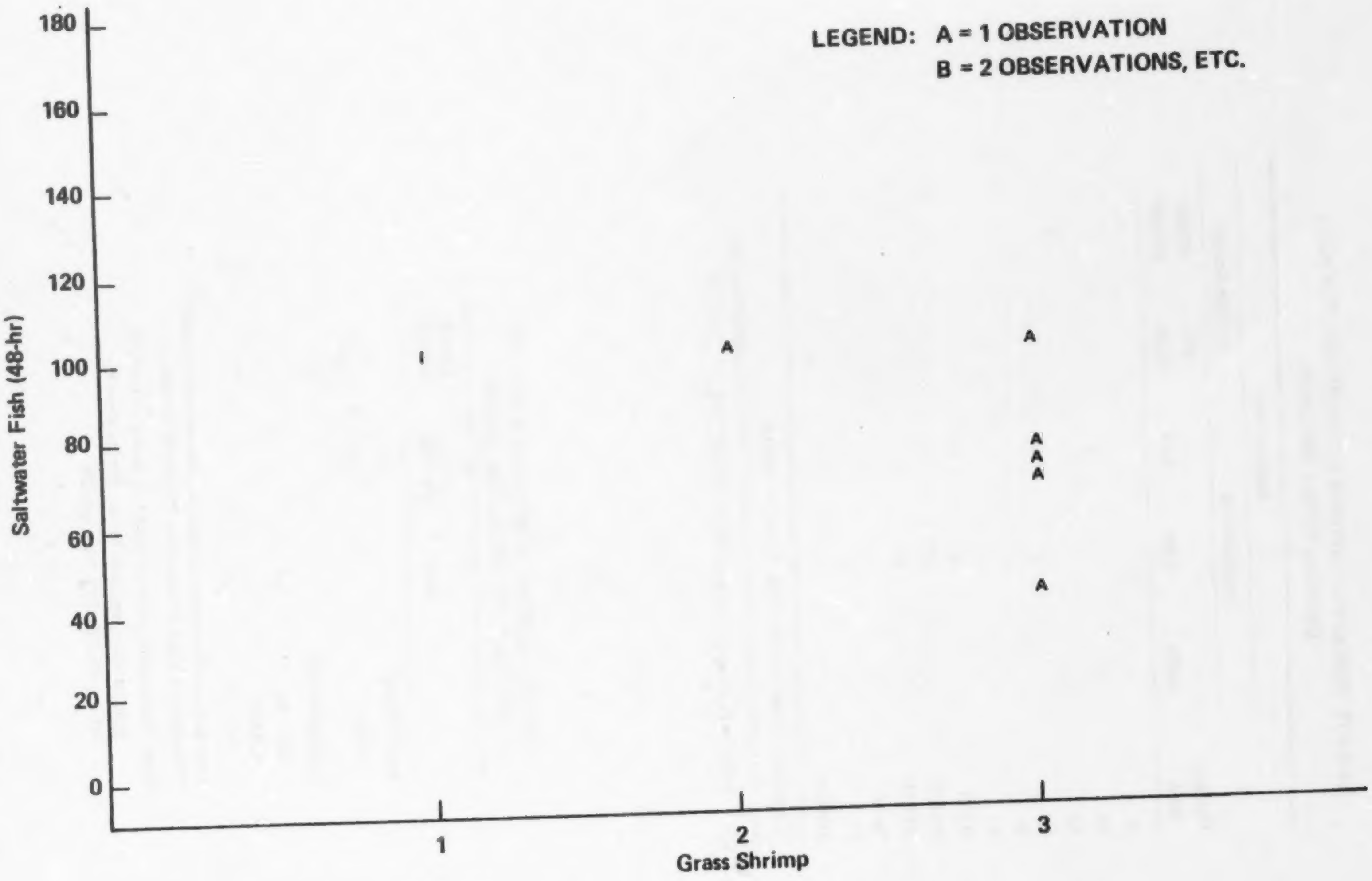


Figure 8. Scatter plot showing negative slope.



NOTE: 36 OBS HAD MISSING VALUES

Figure 9. Scatter plot showing one of several miscellaneous patterns.

TABLE 22. SUMMARY OF PATTERNS IN SELECTED SCATTER PLOTS, CHEMICAL TESTS V. BIOASSAYS

Chemical tests	Biological tests				
	Health-Related			Ecology-Related	
	AMES	RAM	RAT	FW FISH	GRASS SHRIMP
Bi	X				
Pb	X		X		
Cd					X
Fe		X			
Si		X			
Mg		X			
MEG1		X			
MEG23		X*			
MEG25		X*			
As-AA	X				
pH		X			
Organics				X	

*Correlation is based on fewer than 10 pairs of numbers.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.

TABLE 23. SUMMARY OF PATTERNS IN SELECTED SCATTER PLOTS, BIOASSAYS V. BIOASSAYS

	RAM	SW FISH	GRASS SHRIMP
Health-Related			
RAM		X*	X*
Ecology-Related			
SW FISH	X*		
GRASS SHRIMP	X*		

*Correlation is based on fewer than 10 pairs of numbers.

Note: The transformation $x = \log(c + 1)$, where c = chemical concentration, was made for all chemical elements, MEG1–MEG26, $SO_3^=$, NH_3, and CN^-.

is combined with the ecology-related saltwater fish and grass shrimp parameters.

4.4 STEPWISE REGRESSIONS

4.4.1 Biological Tests V. Chemical Data

Stepwise regression is commonly used by researchers to indicate which variables out of a large group of variables appear to be the most important in predicting the data for a given variable (e.g., AMES2). The procedure assumes that a linear relationship exists between the dependent variable (AMES2) and the independent variable (e.g., Bi). For example,

$$\text{AMES} = a + B_1 (\text{Bi}_i) + B_2 (\text{C8}_i) + B_3 (\text{NO}_2) + e_i$$

where a, B_1, B_2, and B_3 are unknown parameters and e_i is a random error term.

In brief, the stepwise regression procedure used is as follows. The stepwise computer program finds the single-variable model (i.e., AMES2 predicted by only one variable) that produces the largest R^2 statistic (where R^2 is the square of the multiple correlation coefficient). After entering the variable with the largest R^2, the program uses the partial correlation coefficients to select the next variable to enter the regression. That is, the program enters the variable with the highest partial correlation coefficient with AMES2 (given that the variable with the largest R^2 is already in the model). An F test is performed to determine if the variable to be entered has a probability greater than the specified "significance level for entry." After a variable is added, the program looks at all the variables already included in the model and computes a partial F-statistic to determine if these variables should remain the model. Any variable not producing a partial F significant at the specified "significance level for inclusion" is then deleted from the model. The process then continues by determining if any other variables should be added to the regression. The process terminates when no variable meets the conditions for inclusion or when the next variable to be added to the model is one just previously deleted from it. For the present analysis, all variables in the final regression model were deemed significant at the 0.10 level of significance.

Stepwise regressions were run to determine which of the chemical test results (151 variables) would best predict data for the biological tests AMES2, RAM, RODENT, grass shrimp, and freshwater fish. The Litton-grouped bioassay results were considered here. It was not possible to run regressions to predict the results of the tests WI-38, CHO, freshwater algal, and *Daphnia* because of limited sample sizes. Table 24 presents the biological test data that were available for these stepwise regressions. It is important to note from Table 24 the limited variation in the various biological tests: (1) AMES2 has only 3 values out of 33 that are not equal to 1; (2) all RODENT values are equal to 1; and (3) RAM, grass shrimp, and freshwater fish have only 15 or 16 values each and they vary from 1 to 3. This lack of variability certainly makes stepwise regression results suspect and of questionable value in the present context. However, the results are presented here in the interest of completeness. Also, it is important to note in running the regressions that missing chemical data were set equal to zero. This is certainly a questionable procedure but some compromise had to be made because of the large amount of missing chemical data.

The results of running the stepwise regressions were as follows:

1. AMES2 (sample size = 33)

   Best predicted by (the logarithm of) Bi. The regression equation with Bi had an $R^2 = 0.96$ ($R^2 = [\text{correlation}]^2$ and indicates the amount of variation accounted for by the regression equation). Because Bi accounted for almost all of the variation in AMES2, other chemical predictor variables were not considered. However, it is important to note that several other chemical variables by themselves would also account for over 90 percent of the variation in AMES2.

2. RAM (sample size = 16)

Order of chemical variables selected	R^2 at each step
NH_3	.53
Ca	.69
GC8	.82
Sussol	.87
MEG2	.91

TABLE 24. BIOLOGICAL TEST RESULTS USING LITTON QUANTITATION

STUDY	SAMPLE	AMES2	RAM	WI-38	CHO	RODENT	FWALGAL	GRASS SHRIMP	FWFISH	DAPHNIA
6	02	4	2	•	•	•	•	•	•	•
6	03	1	3	3	•	1	•	•	•	•
6	04	1	1	•	•	1	•	•	•	•
6	05	1	1	•	•	1	•	•	•	•
10	09	•	1	•	•	1	2	1	2	2
10	08	1	1	•	•	1	•	•	•	•
10	07	•	1	•	•	1	2	2	1	1
10	06	1	1	•	•	1	•	•	•	•
10	04	2	1	•	•	•	•	•	•	•
10	03	2	2	•	•	•	•	•	•	•
10	02	1	1	•	•	1	•	•	•	•
10	01	1	1	•	•	1	•	•	•	•
19	0A	1	•	•	•	1	•	3	2	•
19	0B	1	•	•	•	1	•	1	1	•
19	0C	1	•	•	•	1	•	3	2	•
19	0E	1	•	•	•	1	•	•	•	•
19	0F	1	•	•	•	1	•	1	1	•
19	0G	1	•	•	•	1	•	1	1	•
19	0K	1	•	•	•	1	•	1	1	•
19	0L	1	2	2	2	1	•	1	2	•
19	0N	1	2	2	2	1	•	3	3	•
19	0S	1	•	•	•	1	•	1	1	•
19	0T	1	•	•	•	1	•	3	2	•
19	0U	1	•	•	•	1	•	1	1	•
19	0V	1	•	•	•	1	•	•	•	•
19	0W	1	•	•	•	1	•	3	3	•
19	0X	1	•	•	•	1	•	1	1	•
19	0D	1	•	•	•	1	•	•	•	•
19	0H	1	•	•	•	1	•	•	•	•
19	0J	1	•	•	•	1	•	•	•	•
19	0M	1	2	1	1	1	•	•	•	•
19	0P	1	•	•	•	1	•	•	•	•
19	0R	1	1	1	3	1	•	•	•	•
19	0Y	1	•	•	•	1	•	•	•	•
19	0Z	1	•	•	•	1	•	•	•	•
19	01	1	•	•	•	•	•	•	•	•

• = Missing value.
1 = No detectable response
2 = Low response
3 = Moderate response
4 = High response

(That is, a regression equation with NH3, Ca, C8, Sussol, and MEG2 accounted for 91 percent of the variability in RAM.)

3. RODENT (sample size = 32)
   No variables selected because all RODENT values = 1.
4. Grass shrimp (sample size = 15)

Order of chemical variables selected	R^2 at each step
Organics	.20
Acidity	.37

5. Freshwater fish (sample size = 15)

Order of chemical variables selected	R^2 at each step
Cr^{++}	.29
MEG18	.54
C7	.72

4.4.2 AMES2 V. Its Component Strains

Table 25 presents a data listing of AMES2 and its component strains. These data were used to run stepwise regressions designed to predict AMES2 from the strains. In running these regressions, TA1538M and TA1538P were not considered because of missing data. The results were as follows (sample size = 32):

Order of strains selected	R^2 at each step
TA98P	.82
TA98M	.91
TA1535M	.94

Thus, three strains accounted for 94 percent of the variation in AMES2. Of course the caveats listed previously also apply to the present analysis. Figure 4 (p. 38) presents a plot of TA98P v. AMES2. This plot shows that the high correlation is essentially based on only one data point.

4.4.3 Relationships Between the Biological Tests

Table 24 indicates the limited number of samples for which data are available on more than one biological test. Accordingly, stepwise regressions were not considered feasible for the purpose of predicting the results

TABLE 25. AMES2 AND ITS COMPONENT STRAINS BY STUDY*

STUDY	SAMPLE	AMES2	TA1535M	TA1535P	TA1537M	TA1537P	TA98M	TA98P	TA100M	TA100P	TA1538M	TA1538P
6	02	4	1.2	2.0	2.2	17.3	1.5	23.9	1.4	4.8	1.5	33.9
6	03	1	1.1	1.1	3.4	1.5	0.9	1.4	1.1	1.0	1.4	1.2
6	04	1	1.2	1.4	1.8	1.1	1.3	1.1	1.2	1.1	1.5	1.0
6	05	1	0.9	1.9	1.6	1.1	1.4	0.8	1.1	1.1	1.2	1.1
10	09	•	•	•	•	•	•	•	•	•	•	•
10	08	1	1.1	1.3	1.2	1.0	1.1	1.2	1.3	1.0	1.5	1.5
10	07	•	•	•	•	•	•	•	•	•	•	•
10	06	1	1.1	1.0	1.2	0.8	1.1	0.8	1.3	0.8	0.8	0.8
10	04	2	0.8	1.3	2.6	1.6	4.2	2.1	1.3	0.8	3.9	1.5
10	03	2	1.8	1.5	1.5	1.1	2.6	1.4	1.6	1.1	6.9	2.7
10	02	1	1.7	1.1	1.5	2.6	1.0	1.3	1.3	1.0	1.3	0.8
10	01	1	1.3	1.0	1.0	1.2	1.3	1.3	1.2	1.2	2.0	0.8
19	0A	1	1.7	1.5	1.0	1.1	1.2	0.8	1.2	1.1	•	•
19	0B	1	1.6	1.2	1.6	1.0	1.2	1.0	1.1	1.1	•	•
19	0C	1	2.2	1.5	1.9	1.2	1.0	3.2	1.2	1.0	•	•
19	0E	1	•	•	•	•	•	•	•	•	•	•
19	0F	1	1.7	1.5	1.1	9.1	1.3	1.1	1.2	1.3	•	•
19	0G	1	1.0	0.7	1.3	1.2	1.1	1.4	1.2	1.1	•	•
19	0K	1	2.4	1.2	1.5	2.7	1.0	0.9	1.0	0.9	•	•
19	0L	1	1.5	1.3	1.6	1.5	1.1	1.1	1.0	1.1	•	•
19	0N	1	1.9	1.5	1.0	1.2	1.7	1.3	1.3	1.2	•	•
19	0S	1	1.7	1.5	1.3	1.4	1.7	2.1	1.3	1.2	•	•
19	0T	1	1.7	1.2	1.0	1.2	1.3	1.1	1.2	1.0	•	•
19	0U	1	1.7	1.4	1.7	1.7	1.5	0.9	1.2	1.1	•	•
19	0V	1	1.2	0.7	1.3	1.4	0.8	1.1	1.2	1.1	•	•
19	0W	1	1.3	1.3	1.7	2.2	1.3	1.3	1.1	1.3	•	•
19	0X	1	1.9	1.5	1.2	1.3	1.6	0.9	1.2	1.0	•	•
19	0D	1	5.2	2.3	2.6	3.4	2.6	2.6	1.6	1.2	•	•
19	0H	1	1.5	1.4	1.2	1.4	1.3	0.9	1.1	1.0	•	•
19	0J	1	1.3	1.4	1.7	1.1	0.8	1.3	1.1	1.0	•	•
19	0M	1	1.4	0.9	1.4	1.9	0.9	1.3	1.1	1.0	•	•
19	0P	1	1.7	1.3	1.6	1.4	1.0	1.0	1.3	1.2	•	•
19	0R	1	1.6	1.4	1.6	1.5	1.5	1.0	1.2	0.9	•	•
19	0Y	1	2.0	1.8	1.6	1.7	1.5	1.6	1.1	1.1	•	•
19	0Z	1	1.2	0.8	1.8	0.8	0.9	1.8	1.2	1.1	•	•

• = Missing value.

1 = No detectable response

2 = Moderate response

4 = High response

*Numbers reported for component strains are maximum mutagenic ratios (see pp. 103-107 for details).

of one biological test from the other tests. Unfortunately, the limited variation and small sample sizes in the tests make these correlations rather small except for the grass shrimp-freshwater fish combination.

4.5 PROBIT ANALYSIS

A transformation can be made to turn nonlinear regressions between two variables into linear regressions. The logarithm of the variable representing dosage and the probit of the variable representing response are used.

The probit procedure assumes a normal distribution of the data, and calculates maximum likelihood estimates of the slope, intercept, and natural (threshold) response rates for biological data. A thorough description of the probit analysis procedure can be found in Finney, 1952.[13] Probit analysis was performed on dose-response data for ATP content and viability in the RAM test. Data from studies 06, 10, and 19 were considered together. The average ATP content and average viability at five dosage levels were entered into the SAS PROBIT procedure.

The SAS PROBIT Procedure was run at Triangle Universities Computation Center (TUCC) and plots of all data on the same scale were examined and compared with the probit analysis. A check (✓) on Table 26 indicates that a toxic response was (visually) evident from examination of the log-dose-response plot; that is, viability or ATP level decreased as dosage of the sample increased, in comparison to the controls.

The slope of the probit line, as shown in the SAS printout, is given in Table 26; however, the slope value was not a good indicator for this test because each sample had a different intercept. For instance, a sample with high toxicity at the initially low dose could have a small slope and a high toxicity. A sample that showed a response at a moderate or high dose might have a greater slope value yet actually be less toxic than the first case.

Where a dose-response plot did not show a toxic response or where confidence values on the LD_{50} at the 95 percent level ($\bar{X} \pm 2S$) showed a very high or infinite spread, and where the absolute values of slope value were very low (<0.15), the toxicity value ($1/LD_{50}$) was entered as zero. The toxicity value was entered as $1/LD_{50}$ so that very low LD_{50} values (essentially nontoxic by this test) could be entered as zero. By using the reciprocal of the LD_{50} value, it was also possible to obtain a positive value for

TABLE 26. PROBIT DATA ANALYSIS, RAM CYTOTOXICITY TEST

Sample	Encoded sample no.	Viability				ATP			
		Slope[*]	LD_{50}	Plot shows toxicity	$1/LD_{50}$	Slope[*]	LD_{50}	Plot shows toxicity	$1/LD_{50}$
Separator tar	0602	- .664	5.495	√	0.182	- 1.216	6.049	√	0.165
Separator liquor	0603	-1.539	2.787	√	0.359	High value	No probit	√	N/A
Gasifier ash	0604	-0.042	36.930	--	0	- 0.118	15.481	--	0
Cyclone dust	0605	-0.081	12.889	--	0	≅0	No probit	--	0
Fine particulate	1003	-0.986	7.079	√	0.141	- 0.651	6.405	√	0.156
Cyclone dust	1006	- 1.606	7.264	√	0.138	- 0.310	8.089	√	0.124
Cyclone leachate	1007	-0.158	10.918	√	0.092	- 0.199	7.807	√	0.128
Bed leachate	1009	-0.059	33.346	--	0	- 0.252	8.182	√	0.122
Plant A, filtered	190AF	-0.028	29.410	--	0	- 0.207	8.631	√	0.159
Plant B, filtered	190BF	-0.0406	39.128	--	0	- 0.184	11.391	√	0.088
Plant C, filtered	190CF	-0.258	5.915	√	0.169	- 0.779	6.153	√	0.163
Plant D, filtered	190DF	-0.033	46.960	--	0	- 0.148	21.401	--	0
Plant D, unfiltered	190DU	-0.007	109.269	--	0	≅0	No probit	√	0
Plant F, filtered	190FF	0.033	- 39.710	--	0	- 0.190	8.768	√	0.114
Plant F, filtered (retest)	190HF	-0.109	7.073	--	0[†]	- 0.838	5.586	√	0.179[†]
Plant H, filtered	190HF	-0.019	63.273	--	0[†]	- 0.191	6.745	√	0.148[†]
Plant J, filtered	190JF	-0.107	13.050	--	0	≅0	No probit	--	0
Plant K, filtered	190KF	0.013	-118.194	--	0	- 0.248	11.859	√	0.084
Plant L, filtered	190LF	0.402	-1.422	--	0[‡]	- 0.584	5.738	√	0.174
Plant M, filtered	190MF	-0.219	6.016	√	0.166	- 0.605	8.039	√	0.124
Plant M, unfiltered	190MU	-0.011	108.785	--	0	- 0.286	5.944	√	0.168
Plant N, filtered	190NF	-0.146	12.254	--	0	- 1.122	4.744	√	0.211
Plant N, unfiltered	190NU	-0.396	7.481	√	0.134	- 0.578	4.756	√	0.210
Plant P, filtered	190PF	-0.096	25.600	--	0	≅0	No probit	--	0
Plant R, filtered	190RF	-0.034	53.844	--	0	- 0.140	14.963	--	0
Plant T, filtered	190TF	-0.097	-17.091	--	0	- 0.210	7.604	√	0.131
Plant U, filtered	190UF	0.072	-12.568	--	0	0.007	-90.553	--	0
Plant W, filtered	190WF	-0.181	8.910	√	0.112	- 0.565	6.569	√	0.152
Plant X, filtered	190XF	0.534	-0.364	--	0[‡]	- 0.244	7.597	√	0.132
Plant Y, filtered	190YF	-0.228	7.410	√	0.135	≅0	No probit	--	0
Plant Y, unfiltered	190YU	-0.332	8.316	√	0.120	- 0.109	9.248	--	0
Plant Z, filtered	190ZF	-0.284	7.619	√	0.131	- 0.439	8.754	√	0.114
Plant G, filtered	190GF	≅0	No probit	--	0	0.164	11.545	√	0.087
Plant V, filtered	190VF	≅0	No probit	--	0	0.105	1.600	--	0
Plant P, unfiltered	190PU	≅0	No probit	--	0	- 3.44	6.187	√	0.161

[*] If $|slope| < 0.15$ or plot does not show toxic response and confidence limits infinite, entered $1/LD_{50}$ value as ϕ in Fortran program.

[†] Entered average of values.

[‡] Confidence limits not $\propto$, but values negative at −25 (lower limit).

the correlation; that is, as toxicity increases, the numerical value for toxicity increases.

There had been some speculation as to the effects of field-filtering samples on the toxicity (biological response) of these samples. From the data set for the textile effluents, Study 19, there does not seem to be a pattern of toxicity values showing that unfiltered samples are more toxic than filtered samples. Table 27 shows the $1/LD_{50}$ values for filtered and unfiltered effluents for the five textile effluents analyzed in this manner. In Table 27, there is no evident trend showing filtered samples to be less toxic than unfiltered samples, as indicated by the RAM test.

4.6 ANALYSIS OF THE DATA SET THROUGH USE OF MODELS

Various systems or models have been proposed to aid in the interpretation and analysis of data from the Environmental Assessment Program. All of these systems are based on the MEG/MATE values,[14] [15] on Threshold Limit Values (TLV's), or on legal emission standards.

Monsanto Research Corporation (MRC), in conjunction with IERL, developed the Source Severity Model, which ratios levels of pollutants found by analysis of effluent samples to the acceptable concentrations of these pollutants. The source severity factor (S) is defined as "the ratio of the calculated maximum ground level concentrations of the pollutant species to the level at which a potential environmental hazard exists."[16] The maximum ground level concentration for gaseous emissions from point sources is calculated by the simple Gaussian Plume equation. The acceptable pollutant level is estimated as the TLV/300 for those pollutants for which no Federal regulations exist.

In these cases, S is calculated as:

$$S = \frac{5.50}{(TLV)h^2},$$

where

TLV = threshold limit value, g/m^3,
h = stack height, meters.

The acceptable pollutant level is the ambient air quality standard for noncriteria pollutants.

TABLE 27. TOXICITY * OF FILTERED AND UNFILTERED TEXTILE EFFLUENTS

Plant	Unfiltered	Filtered	Toxicity unfiltered > toxicity filtered?
Cell viability			
D	0	0	SAME
M	0	.166	NO
N	.134	0	YES
Y	.120	.135	NO
P	N/A	0	N/A
ATP			
D	0	0	SAME
M	.168	.124	YES
N	.210	.211	NO (≈SAME)
Y	0	0	SAME
P	.161	0	YES

*Toxicity expressed as $1/LD_{50}$ in the RAM test.

Equations for calculating S for the five criteria air pollutants are as follows:

Particulates	$S = 70\ Qh^{-2}$
SO_x	$S = 50\ Qh^{-2}$
NO_x	$S = 315\ Qh^{-2.1}$
Hydrocarbons	$S = 162.5\ Qh^{-2}$
CO	$S = 0.78\ Qh^{-2}$

where Q = emission rate, g/s.

For discharges to water, the source severity factor is based on the drinking water standards and is calculated as follows:

$$S = \frac{V_D C_D + S_G f_1 f_2}{V_R D} ,$$

where

V_D = discharge flow rate, m^3/s;
C_D = discharge concentration, g/m^3;
S_G = leachable solid waste generation, g/s;
f_1 = fraction of the solid waste to water;
f_2 = fraction of the material in the solid waste;
V_R = river flow rate, m^3/s;
D = drinking water standard, g/m^3.

It can be seen readily that all of the source severity equations follow the same general concept:

$$\text{Estimation of hazard or severity} = \frac{\text{Concentration found in effluent or emission} \times \text{Dilution factor}}{\text{Estimation of acceptable level}} .$$

The Source Assessment Models (SAM's) developed for the IERL by the Acurex Corporation follow this same concept and expand the list of materials for which estimations of an acceptable environmental discharge level are available. This expanded list, herein called the MEG/MATE value list,[14] [15] was prepared for IERL by the Research Triangle Institute. This comprehensive list incorporates drinking water standards, emission standards, TLV information, and other information available from whole animal tests (LD_{50}'s) and other toxicity tests. MATE values are estimations of an acceptable discharge level and MEG values are estimates of permissible levels for long-term exposure in the environment. These values are given as concentrations, for health-related and ecology-related concerns, for solid, liquid, and/or gaseous forms of these compounds for which information is available. The MEG/MATE value list is being revised and expanded as more information from research efforts becomes available.

The SAM's are comprised of a series of models. SAM/IA,[17] the simplest model, is a ratio of concentration of material found to the appropriate MATE value for that material. If a MATE value is not available for a certain material, the lowest MATE value in the MEG category (category of similar compounds, such as methane, ethane, propane) is used; this is a worst-case assumption. In the SAM/IA model, these MATE ratios can be summed to give a potential degree-of-hazard value (PDOH) for any given effluent or emission stream. Multiplying the PDOH by the discharge rate gives the toxic unit discharge rate (TUDR), a unitless measure that can be used to compare dissimilar effluents or emission streams.

SAM/IB, the Source Assessment Model for bioassays, is still being developed. An early publication on SAM/IB[18] described appropriate reporting formats for many of the bioassays used in Level 1 of the Environmental Assessment Program.

SAM/I,[19] recently circulated in draft form, incorporates dilution factors appropriate to the source of discharge to the concepts developed in SAM/IA: MEG ratios, PDOH's and TUDR's. SAM/I is appropriate for summarizing Level 1 or Level 2 environmental assessment data. The SAM models are intended as uniform protocols for data interpretation and can be used to rank individual discharges, establish priorities, identify problem areas, and provide a means of comparing control options.

The data set of samples from the three pilot studies was entered in the SAM/IA model. Data from Study 15, the SASS evaluation, were not entered because many chemical parameters were missing. MATE ratios were calculated for all chemical parameters for which analysis had been performed. A possible source of error here could be the inclusion of more ratios for some samples where more analyses were performed; but the establishment of a uniform protocol for analysis should eliminate this error in future work. The ratios were summed for each sample to give a PDOH value for that sample. The health-related and ecology-related PDOH values for each sample are presented in Tables 28 and 29. These tables also show the bioassay results in the Litton-grouped forms,[11] reported as nondetectable (ND), low (L), moderate (M), or high (H).

TABLE 28. HEALTH EFFECTS: SUMMARY OF CHEMICAL AND BIOLOGICAL TEST RESULTS*

Study	Sample	1a PDOH	1b PDOH	2 AMES	3 RAM	4 WI-38	5 RAT
Coal gasifier	Separator liquor	6.10×10^7	7.7854	N	M	†	N
Fluidized-bed combustor	Bed reject leachate	1.16×10^6	6.0644	†	N	†	N
Coal gasifier	Separator tar	1.01×10^6	6.0041	H	L	†	N
Fluidized-bed combustor	Cyclone leachate	6.66×10^5	5.8238	†	N	†	N
Textile effluent	Plant L	8.36×10^3	3.9224	N	M	L	N
Textile effluent	Plant W	4.99×10^3	3.6984	N	L	†	N
Textile effluent	Plant T	3.35×10^3	3.5245	N	M	†	N
Textile effluent	Plant N	3.28×10^3	3.5161	N	M	L	N
Coal gasifier	Gasifier ash	1.72×10^3	3.2343	N	N	†	N
Textile effluent	Plant U	8.86×10^2	2.9474	N	N	†	N
Textile effluent	Plant S	8.35×10^2	2.9217	N	†	†	N
Fluidized-bed combustor	Fine particulates	7.00×10^2	2.8451	L	L	†	N
Fluidized-bed combustor	Feed coal	5.33×10^2	2.7267	N	N	†	N
Textile effluent	Plant V	5.19×10^2	2.7152	N	N	†	N
Textile effluent	Plant F	4.52×10^2	2.6551	N	L	†	N
Fluidized-bed combustor	Cyclone dust	3.80×10^2	2.5798	N	N	†	N
Fluidized-bed combustor	Coarse particulates	3.43×10^2	2.5353	L	N	†	N
Textile effluent	Plant B	3.30×10^2	2.5185	N	N	†	N
Fluidized-bed combustor	Bed reject	1.58×10^2	2.1987	N	N	†	N
Textile effluent	Plant K	1.43×10^2	2.1553	N	N	†	N
Textile effluent	Plant A	1.14×10^2	2.0569	N	N	†	N
Textile effluent	Plant C	9.90×10^1	1.9956	N	L	†	N
Textile effluent	Plant G	9.40×10^1	1.9731	N	N	†	N
Textile effluent	Plant X	3.60×10^1	1.5563	N	L	†	N
Textile effluent	Plant E	3.30×10^1	1.5185	N	N	†	N
Fluidized-bed combustor	Dolomite	2.30×10^1	1.3617	N	N	†	N
Coal gasifier	Cyclone dust	1.70×10^1	1.2304	N	N	†	N

H = HIGH toxicity rating.
M = MODERATE toxicity rating.
L = LOW toxicity rating.
N = No detectable toxicity.

1a = PDOH = potential degree of hazard.
1b = PDOH = potential degree of hazard (LOG_{10})
2 = AMES = mutagenicity test
3 = RAM = rabbit aveolar macrophage.
4 = WI-38 = human embryonic lung cells.
5 = RAT = rodent acute toxicity.

*Subsequent to the completion of this work, the term "Potential Degree of Hazard" or PDOH was changed to "Discharge Severity" or DS.

†Data not available.

TABLE 29. ECOLOGICAL EFFECTS: SUMMARY OF CHEMICAL AND BIOLOGICAL TEST RESULTS*

Study	Sample	6a POOH	6b PDOH	7 FW ALGAL	8 FW FISH	9 DAPHNIA	10 SW ALGAL	11 SW FISH	12 GRASS SHRIMP
Fluidized-bed combustor	Bed reject leachate	1.50×10^{8}	8.1763	L	L	L	†	N	N
Coal gasifier	Separator liquor	6.94×10^{7}	7.8415	H	H	H	M	H	H
Fluidized-bed combustor	Fine particulates	1.01×10^{6}	6.0055	†	†	†	†	†	†
Coal gasifier	Separator tar	2.90×10^{5}	5.4624	†	†	†	†	†	†
Fluidized-bed combustor	Feed coal	2.67×10^{5}	5.4267	†	†	†	†	†	†
Textile effluent	Plant N	1.51×10^{5}	5.1806	M	L	H	M	L	L
Fluidized-bed combustor	Coarse particulates	8.93×10^{4}	4.9513	†	†	†	†	†	†
Coal gasifier	Cyclone dust	8.06×10^{4}	4.9065	†	†	†	†	†	†
Fluidized-bed combustor	Cyclone leachate	6.20×10^{4}	4.7922	L	N	N	†	N	L
Textile effluent	Plant L	6.07×10^{4}	4.7830	N	L	L	M	N	N
Textile effluent	Plant C	3.62×10^{4}	4.5589	N	L	L	L	L	L
Textile effluent	Plant B	3.05×10^{4}	4.4836	L	N	N	N	N	N
Textile effluent	Plant E	2.91×10^{4}	4.4638	M	N	M	L	N	N
Fluidized-bed combustor	Cyclone dust	2.59×10^{4}	4.4137	†	†	†	†	†	†
Textile effluent	Plant V	2.54×10^{4}	4.4051	N	L	M	L	†	†
Textile effluent	Plant F	2.23×10^{4}	4.3482	N	N	L	L	N	N
Textile effluent	Plant T	1.56×10^{4}	4.1939	N	L	N	L	L	L
Textile effluent	Plant U	1.46×10^{4}	4.1646	N	N	L	N	N	N
Textile effluent	Plant A	1.36×10^{4}	4.1345	N	L	M	†	L	L
Textile effluent	Plant G	1.15×10^{4}	4.0618	N	L	L	L	N	N
Textile effluent	Plant K	1.06×10^{4}	4.0249	N	N	N	L	N	N
Textile effluent	Plant S	9.48×10^{3}	3.9770	N	N	†	N	N	N
Coal gasifier	Gasifier ash	9.30×10^{3}	3.9683	†	†	†	†	†	†
Textile effluent	Plant W	5.62×10^{3}	3.7494	N	L	M	L	L	L
Fluidized-bed combustor	Bed reject	2.68×10^{3}	3.4275	†	†	†	†	†	†
Fluidized-bed combustor	Dolomite	4.78×10^{2}	2.6794	†	†	†	†	†	†
Textile effluent	Plant X	3.43×10^{2}	2.5353	N	N	N	N	N	N

H = HIGH toxicity rating.
M = MODERATE toxicity rating.
L = LOW toxicity rating.
N = No detectable toxicity.

6a = PDOH = potential degree of hazard.
6b = PDOH = potential degree of hazard (LOG_{10}).
7 = FW ALGAL = fresh water algal.
8 = FW FISH = fathead minnow.
9 = FW DAPHNIA = fresh water invertebrate.
10 = SW ALGAL = marine algal.
11 = SW FISH = marine sheepshead minnow.
12 = SW GRASS SHRIMP = saltwater shrimp.

*Subsequent to the completion of this work, the term "Potential Degree of Hazard" or PDOH was changed to "Discharge Severity" or DS and the response ranges for aquatic ecological tests were redefined based on recommendations from EPA ecologists.

†Data not available.

Several observations can be made from Tables 28 and 29. There is generally good agreement between health-related PDOH values in Table 28 and health-related biotest results. Such an agreement is also noted for the ecology-related tests in Table 29 but there are notable exceptions to this pattern of responses; for example, Plant W, Table 29, shows positive bioassay responses for five of the six ecological biotests but its PDOH value is the fourth from the lowest in a series of 27 samples. For the purpose of comparing these two methods (the chemically based PDOH values and the actual bioassay results) to determine hazard, linear regression analyses were performed to compare each bioassay with the corresponding PDOH value. The correlations are presented in Table 30.

It can be observed from Tables 28 and 29 that neither chemistry alone nor bioassay alone can predict the overall hazard of an effluent or emission, but that these two test systems, taken together, can thoroughly evaluate a material both for content of known hazardous chemicals and for effect of a variety of biological receptors. It should be noted that each bioassay was designed to measure a different endpoint, so it is not appropriate to sum the various response levels across bioassays.

4.7 OTHER INVESTIGATORS' ANALYSES OF THIS DATA SET

Two other organizations investigated these data from the four IERL environmental assessments for patterns and for correlations among the various parameters. Dr. James R. Hoyland of Battelle-Columbus Laboratories performed a computerized pattern recognition analysis on the data and Don Lewis of EPA-RTP analyzed the data for nonparametric correlations.

A preliminary report from Dr. Hoyland on his work, presented in Appendix D, deals with the analysis of this data set via a computer program for recognition of patterns and relationships. This pattern recognition program performs computations similar to classical multivariate analysis on grouped or "discretized" data, determining whether one or more groups of parameters are correlated with one or several other groups of parameters. Dr. Hoyland found that this data set was not sufficiently large or, in many cases, sufficiently complete to apply his program for pattern recognition and gain statistically significant results. As discussed on page D-6 of this document, the following relationships were very tentatively suggested by the data:

TABLE 30. ASSOCIATIONS BETWEEN BIOASSAY RESULTS AND HAZARD ESTIMATIONS BASED ON CHEMICAL ANALYSIS

Correlation coefficients			
Health-related		**Ecology-related**	
(PDOH v. bioassay*)		(PDOH v. bioassay*)	
AMES	.456 (n=25)	FW ALGAL	.609 (n=18)
RAM	.427 (n=26)	FW FISH	.599 (n=18)
WI-38	NA (n=2)	DAPHNIA	.485 (n=17)
RAT	NA (y=1)	SW ALGAL	.710 (n=15)
		SW FISH	.592 (n=17)
		GRASS SHRIMP	.593 (n=17)

Note: The bioassay results were quantified as follows:

High = 1000	Low = 10
Moderate = 100	Nondetectable = 1

TABLE 31. RANK CORRELATIONS IN NONTEXTILE DATA

Biological	Chemical
AMES 1 positively correlated with	Bi, Pb, La, MEG2, MEG15
AMES 2 negatively correlated with	Cl, $CO_3^=$; $SO_3^=$
AMES 2 positively correlated with	F
RAM 2 positively correlated with	I, MEG1, MEG21, MEG25, Hg-AA
RAM 1000 & RAM ATP negatively correlated with	MEG1, MEG21, MEG25

TABLE 32. RANK CORRELATIONS IN TEXTILE DATA

RAT	positively correlated with Pb, Zr, Fe
RAT	negatively correlated with Ta, Yb, MEG1, LC4
SW ALGAL	positively correlated with Sm, LC2
SW ALGAL	negatively correlated with La, Zr, V, NO_3^-
GRASS SHRIMP	positively correlated with Pr, Y, Se, Ni
GRASS SHRIMP	negatively correlated with Os, Eu, Be, LC6
FW FISH	positively correlated with Ag, Zr, Y, Sr, Rb, Ni, NO_3
FW FISH	negatively correlated with Dy, Sm, Cl

- $NO_3^=$ and Co related to RAM.
- LC8, Ca, and Co related to RAM-ATP.
- S related to freshwater algae.

Mr. Don Lewis, a biostatistician at EPA-RTP, has also examined this data set for possible relationships between chemical concentrations and biological responses. Mr. Lewis suggested in his report, which is presented in Appendix B, that the rank (Spearman) correlation was more appropriate for analysis of this data set because the assumptions of normal distribution and linearity inherent in linear (Pearson) correlation could not be made for environmental data or for biological response. Therefore, he used only the rank (Spearman) correlation in his analysis of the data.

Mr. Lewis grouped the data as textile and nontextile, and he observed substantially lower concentrations of the measured chemical parameters in the textile samples. He stated that the data show "high degrees of variability" even when grouped in this manner. From his correlation analysis, Mr. Lewis concluded that there was no strong association between chemical and biological results. He theorized that this might be due to the statistically small sample set or to the low concentrations of many chemicals (below the biological response level). With these qualifiers, the associations described in Table 31 (rank [Spearman] correlations) were found in the nontextile data. Table 32 describes relationships found in the textile data.

Mr. Lewis examined the relationships among the various strains of Salmonella bacteria used in the Ames test, and he observed that some mutagenic ratios decreased as chemical concentrations increased. This would tend to support the hypothesis that a toxic effect was caused by a chemical constituent(s) as discussed in the section of this report on interpretation of the Ames test. Mr. Lewis performed multiple regression analysis on the Ames strain ratios and found that the best pair of predictors was TA98 (without activation) and TA1538 (with activation), explaining 90 percent of the variation.

In examining the rank correlations among the other biotests, Mr. Lewis found a positive association between freshwater fish and grass shrimp, and a negative correlation between freshwater fish and saltwater algae. As mentioned previously, a more thorough discussion of his work can be found in Appendix B.

4.8 ENGINEERING DATA

Engineering data were available for chemical concentrations of effluent from the FBC miniplant. Although a large amount of data has not been amassed, enough information has been gathered to begin statistical analysis. Out of 163 chemical-source combinations, 128 (79 percent) were measured in Runs 2, 4, and 5. A t-statistic was utilized to determine whether there was a significant difference in concentrations of chemicals in the effluent gases when coal was burned at different temperatures. Run 2 was made at 805° C; Runs 4 and 5 were made at 890° C and 895° C, respectively.

Although conclusions are tentative, a trend in the data has appeared. Significant differences are shown in 24 of the 128 chemical-source combinations examined (Tables 33 and 34). In 20 of these cases (83 percent), a significantly larger amount of a given chemical compound was found at the lower temperature. In the remaining four cases (17 percent), a significantly greater quantity of a particular material was found at the higher temperature. Data for an additional 10 chemical-source combinations appear to show a significant difference by temperature; however, a t-statistic cannot be calculated since the estimate of variance was zero. These combinations are noted in Tables 33 and 34 by a dagger.

Analysis of the data showed that the most significant difference between the high- and low-temperature runs occurred in the GC10 measurement for particulates >3μ; the lower temperature produced more particulates (0.99 confidence level). In terms of classification by chemical, the chloride anion measurement showed several significant differences. The measurements for bed reject leachate and particulates >3μ showed differences at the 0.95 confidence level; measurements for cyclone dust and particulates <3μ showed differences at the 0.90 confidence level. In terms of effluent stream, particulates >3μ showed the most significant difference by temperature. In addition to the GC10 measurement noted above (0.99 level of confidence), the following were significant at the 0.95 level of confidence: GC8, GC9, GC13, and chlorine anion. The LC6 measurement was significant at the 0.90 confidence level. The quality of the data would be improved by recording additional runs, both at the lower and higher temperatures mentioned above.

TABLE 33. EFFECT OF ENGINEERING CONDITIONS IN CHEMICAL CONCENTRATIONS* OF EFFLUENTS FROM FBC MINIPLANT (CLASSIFIED BY CHEMICAL CATEGORY)

Chemical	Source	Run 2 805° C	Run 4 890° C	Run 5 895° C	Level of confidence
CO	Continuous monitor	130	56	53	.95
SO_2	Continuous monitor	151	41	29	.90
O_2	Continuous monitor	7.6%	6.0%	5.5%	.80
CO_2	Continuous monitor	9.8%	12.5%	13.1%	.80
NO_x	Continuous monitor	136	124	119	.80
GC7	Cyclone dust	117	15	41	.80
GC8	Particulate $>3\mu$	340	4	30	.95
GC9	Particulate $>3\mu$	193	12	17	.95
GC10	Particulate $>3\mu$	415	0	5	.99
	Bed reject	13	0	4	.80
GC13	Particulate $>3\mu$	265	1	6	.95
LC2	Cyclone dust	73	12	0	.90
LC3	Cyclone dust	29	0	0	†
LC5	Particulate $<3\mu$	122	0	0	†
LC6	Particulate $>3\mu$	238	0	35	.90
	SASS wash	710	143	0	.80
LC7	Bed reject	70	0	0	†
	Particulate $<3\mu$	139	0	0	†
	Particulate $>3\mu$	926	0	0	†
	SASS wash	426	0	0	†
Cl^-	Bed reject leachate	176	640	620	.95
	Particulate $>3\mu$	970	50	70	.95
	Cyclone dust	240	300	310	.90
	Particulate $<3\mu$	1,000	20	110	.90
F^-	Particulate $<3\mu$	150	320	310	.95
	Bed reject leachate	4.0	2.1	1.7	.80
$SO_4^=$	Bed reject	323,000	261,000	277,000	.80
	Bed reject leachate	1,500	200	200	†
	Cyclone dust	111,000	142,000	142,000	†
	Cyclone dust leachate	900	200	200	†
SO_3^-	Bed reject leachate	3.1	1.5	1.3	.90
	Cyclone dust leachate	2.3	1.5	1.3	.80
NO_3^-	Particulate $<3\mu$	40	10	10	†
S^-	Cyclone dust	100	30	50	.80

*Units are in ppm unless otherwise noted.

†Estimate of variance is 0, so t-statistic cannot be utilized.

TABLE 34. EFFECT OF ENGINEERING CONDITIONS IN CHEMICAL CONCENTRATIONS* OF EFFLUENTS FROM FBC MINIPLANT (CLASSIFIED BY EFFLUENT STREAM)

Source	Chemical	Run 2 805° C	Run 4 890° C	Run 5 895° C	Level of confidence
Bed reject	GC10	13	0	4	.80
	$SO_4^=$	323,000	261,000	277,000	.80
	LC7	70	0	0	†
Bed reject leachate	Cl^-	176	640	620	.95
	SO_3^-	3.1	1.5	1.3	.90
	F^-	4.0	2.1	1.7	.80
	$SO_4^=$	1,500	200	200	†
Cyclone dust	LC2	73	12	0	.90
	Cl^-	240	300	310	.90
	GC7	117	15	41	.80
	S^-	100	30	50	.80
	LC3	29	0	0	†
	$SO_4^=$	111,000	142,000	142,000	†
Cyclone dust leachate	SO_3^-	2.3	1.5	1.3	.80
	$SO_4^=$	900	200	200	†
Particulate <3μ	F^-	150	320	310	.95
	Cl^-	1,000	20	110	.90
	LC5	122	0	0	†
	LC7	139	0	0	†
	NO_3^-	40	10	10	†
Particulate >3μ	GC10	415	0	5	.99
	GC8	340	4	30	.95
	GC9	193	12	17	.95
	GC13	265	1	6	.95
	Cl^-	970	50	70	.95
	LC6	238	0	35	.90
	LC7	926	0	0	†
SASS wash	LC6	710	143	0	.80
	LC7	426	10	0	†
Continuous monitor	CO	130	56	53	.95
	SO_2	151	41	29	.90
	O_2	7.6%	6.0%	5.5%	.80
	CO_2	9.8%	12.5%	13.1%	.80
	NO_x	136	124	119	.80

*Units are in ppm unless otherwise noted.

†Estimate of variance is 0, so t-statistic cannot be calculated.

4.9 ORIGINAL RESULTS COMPARED TO THE LITTON QUANTIFICATION SCHEME

The originally reported results or simple transformations of the raw data, such as sums or ratios, were compared with the grouped values, herein called the Litton scheme.[11] The Litton scheme groups responses from biotests and places these responses in one of four categories: nondetectable, low, moderate, or high. The four response categories were entered into the data set as 1, 2, 3, and 4, respectively. For the purpose of comparing these two methods of quantifying the bioassay results, all data from all studies were considered. Even better correlations would be expected if the samples were grouped by study; such samples could be expected to be more similar than samples from diverse industrial sources. Table 35 shows the data pairs (correlations), the linear correlation coefficient, the significance factor, and the number of data pairs used in the correlation.

Because there were no positive results on the RAT lethality test, and since there were only two data pairs for the freshwater fish 24-hr, the freshwater fish 48-hr, and the Daphnia tests, these results were not appropriate for correlation. All other correlation results except the CHO test showed "good" correlations by the criteria defined for the rest of the statistical analysis in this study (correlation coefficient ≥ 0.50, significance factor <0.05); the CHO test had only four data pairs so these results should not be considered indicative of, or conclusive of, a lack of correlation. Generally, these results show good agreement between the originally reported values such as LD_{50}, EC_{20}, etc., and the summary-grouping scheme proposed by Litton.

4.10 CORRELATIONS AMONG AMES/SALMONELLA STRAINS

The five strains of Salmonella typhimurium used in the Ames test were considered; these are TA1535, TA1537, TA1538, TA98, and TA100. The maximum mutagenic ratio (ratio of maximum revertants to control) for each strain, with and without metabolic activation, was entered in the data set. These numbers were then compared using the linear and rank correlation coefficients. There are two groups of Ames S. typhimurium bacteria detecting two kinds of mutations: TA1535 and TA100 are sensitive to base-pair substitution and TA1537, TA1538, and TA98 are sensitive to frameshift mutation.[20] The data were also examined for these expected patterns of response. Data from all studies were considered together in this effort.

TABLE 35. COMPARISON OF LITTON RANKING SCHEME AND ORIGINALLY REPORTED VALUES

Correlation	Linear correlation coefficient	Significance factor	Number of data pairs	Comment
AMES 2 v. AMES 1	.8417	.0001	23	
RAM v. RAM1000	– .81886	.0001	16	
RAM v. VIABINO	– .74085	.0010	16	
RAM v. ATP	– .74613	.0009	16	
RAM v. PROBVI	.69660	.0118	12	
RAM v. PROBATP	.71964	.0125	11	
WI-38 v. WI-38600	– .98012	.0199	4	
CHO v. CHOMPS	– .87315	.1269	4	
RODENT v. RATLD50	– .0000	1.000	25	No positive results
RODENT v. OTHRAT	– .0000	1.000	25	No positive results
RODENT v. RATWT	– .0000	1.000	26	No positive results
FWALGAL v. FWALGAL	– .0000	––	2	n<3
GRSSHP v. GSHMP24	– .83622	.0001	15	
GRSSHP v. GSHMP48	– .84142	.0001	15	
GRSSHP v. GSHMP96	– .99027	.0001	15	
FWFSH v. FWFSH24	– 1.0000	––	2	n<3
FWFSH v. FWFSH48	– 1.0000	––	2	n<3
FWFSH v. FWFSH96	– .74629	.0022	14	
DAPNA v. DAPH24	– 1.0000	––	2	n<3
DAPNA v. DAPH48	– 1.0000	––	2	n<3

Table 36 shows the linear correlations found when all the Ames test bacterial strains were compared. The checks (√) indicate "good" correlations as defined earlier in the study. The boxes (□) in the upper right corner of each matrix space show where "good" correlations could be expected based on groupings for base-pair substitutions or frameshift mutations. The first number listed in each matrix space is the correlation coefficient, the second number is the significance factor, and the third is the number of data pairs available for this correlation (n). From the table, four "good" correlations that were anticipated were not found; these were 1538M v. 1537M, 98M v. 1537M, 100M v. 1535M, and 100P v. 1535P. (The number designates Ames' strain, P indicates plus S-9 microsomal preparation, and M indicates minus S-9.) A number of other unexpected "good" correlations were found. It should be remembered in analyzing these data that, of the 32 samples tested, only 3 showed a mutagenic response. Of these three samples, two were classified as low mutagenicity and only one as high mutagenicity. Therefore, the actual data set considers 4 points, 3 positives, and 29 samples where the mutagenic ratio was too low to indicate mutagenicity (by the criteria of a threefold increase in revertants over controls).

The actual maximum mutagenic ratios were used here rather than some interpretation of what constitutes a mutagenic response. Although Ames showed a high correlation between positives in his *Salmonella* assay for mutagenicity and positives in classical whole animal tests for carcinogenicity, his data involve single pure compounds rather than the mixtures discussed above. Because more detailed laboratory studies are needed to define and accurately interpret these relationships for complex mixtures, mutagenic ratios were used as a numerical representation of mutagenic response for the mixtures.

These Ames test results are not corrected for toxicity to the bacterial culture, apparently causing anomalies in the interpretation of some raw data. A higher mutagenic ratio (i.e., >3) is noted at a lower dosage but the mutagenic ratio decreases as dosage increases. This could be an actual valid observation and interpretation, or it could mean that the sample is toxic to the bacterial culture, killing bacteria before they can mutate and form colonies. Without toxicity data, it is impossible to know which is the case. (See Tables 37 and 38.) Suggestions for further investigation are discussed in Chapter 5.

TABLE 36. LINEAR CORRELATIONS AMONG THE AMES TEST STRAINS*

	1535M	1535P	1537M	1537P	1538M	1538P	98M	98P	100M	100P
1535M	–	–	–	–	–	–	–	–	–	–
1535P	.54 .0012 32	–	–	–	–	–	–	–	–	–
1537M	.20 .28 32	.28 .12 32	–	–	–	–	–	–	–	–
1537P	.04 .83 32	.40 .02 32	.20 .27 32	–	–	–	–	–	–	–
1538M	.43 .21 10	.10 .78 10	.055 □ .88 10	-.14 .70 10	–	–	–	–	–	–
1538P	-.0029 .99 10	.65 ✓ .04 10	.24 .50 10	.99 ☑ .0001 10	-.083 .02 10	–	–	–	–	–
98M	.22 .22 32	.40 .023 32	.37 □ .040 32	.050 .79 32	.70 ☑ .026 10	-.019 .96 10	–	–	–	–
98P	-.042 .82 32	.37 .036 32	.30 .096 32	.88 ☑ .0001 32	-.11 .77 10	.998 ☑ .0001 10	.075 .68 32	–	–	–
100M	.42 □ .02 32	.37 .037 32	.16 .37 32	.24 .19 32	.73 ✓ .017 10	.33 .34 10	.54 ✓ .0015 32	.29 .11 32	–	–
100P	-.057 .76 32	.38 □ .033 32	.20 .26 32	.90 .0001 32	-.12 .74 10	.99 .0001 10	.0035 .98 32	.98 ✓ .0001 32	.26 .15 32	–

*First number is correlation coefficient; second number is significance factor; third number is N.
P = With (+) activation; M = Without (–) activation.
✓ = Good correlations; □ = Expected to find good correlation.

TABLE 37. COAL GASIFIER, CYCLONE DUST SAMPLE, STRAIN TA1538

μg of Compound per plate	Average revertants per plate without S-9	Average revertants per plate with S-9
0 (DMSO/Control)	13	21
10	19	20
50	18	17
100	13	22
500	10	18
1000	13	20
5000	6	16

TABLE 38. FLUIDIZED-BED COMBUSTOR, COAL SAMPLE, STRAIN TA1537

μg of Compound per plate	Average revertants per plate without S-9	Average revertants per plate with S-9
0 (DMSO/Control)	6	5
10	6	6
50	5	5
100	4	5
500	4	5
1000	2	4
5000	1	4

4.11 COMPARISON OF SCHEMES FOR RANKING SAMPLES USING LEVEL 1 DATA

For the textile effluent study's bioassay program evaluation, an expert panel approach was used. The expert panel was the Bioassay Subcommittee of the Environmental Assessment Steering Committee. Table 39 shows the textile effluent study's samples as they were ranked:

1. By the expert panel,
2. By descending ecology-related PDOH values,
3. By descending health-related PDOH values,
4. By increasing weight gain in the rodent acute toxicity test,
5. By increasing 14-day EC_{20} values in the freshwater algal system,
6. By increasing 96-hr LC_{50} values in the freshwater fish system (fathead minnow),
7. By increasing 48-hr EC_{50} values in the Daphnia system,
8. By increasing 96-hr LC_{50} values in the saltwater fish system (sheepshead minnow),
9. By increasing 96-hr LC_{50} values in the grass shrimp system,
10. By increasing 96-hr EC_{50} values in the saltwater algal system.

So that there is a complete set of information for each sample, only the 15 samples that were analyzed by the Level 1 chemistry are considered here. Several biotests were not considered in this scheme because only a few (or no) samples were tested by these bioassays (RAM, WI-38, CHO) or because the bioassay did not give a positive response for any sample (Ames, RAT-LD_{50}). Five values were missing in the parameters considered in Table 39, and these were assigned a value equal to the mean of the values in the column where the missing value appeared.

For analysis of the data, the experts' rankings were quantified in two different ways. First, each plant was given a numerical rank (denoted as PLANTRNK in Table 40) with a ranking of 1 as most toxic, etc. Second, the three categories assigned to groups of plants by the experts were ranked: most toxic = 2, least toxic = 1, no measurable toxicity = 0. This ranking scheme was denoted as TOXIC in Table 39. A rank correlation was performed on the various other methods of ranking listed above (numbers 2-10) versus TOXIC and versus PLANTRNK. Table 40 presents rank correlations (asterisks denote significance at the 0.05 level) showing a high degree of association

TABLE 39. VARIOUS SCHEMES FOR RANKING TEXTILE STUDY DATA

PLANT	PLANTRNK	TOXIC	ECOLPDOH	HEALPDOH	RATWTGN	FWALGAL	FWFISH	DAPHNIA	SWFISH	GRSSHMP	SWALGAL
N	1.0	2	5.18	3.51	40.7	2	48.8	1.0	47.5	26.3	2.3
A	2.0	2	4.13	2.05	26.2	76	19.0	9.0	62.0	21.2	71.5
W	3.0	2	3.74	3.69	10.3	94	55.2	6.3	37.5	19.6	50.0
C	4.0	2	4.55	1.99	13.6	100	46.5	41.0	69.5	12.8	90.0
T	5.0	2	4.19	3.52	43.9	100	46.5	100.0	68.0	34.5	70.0
V	6.0	2	4.40	2.71	43.4	100	36.0	9.4	84.6	72.5	94.0
L	7.0	2	4.78	3.92	9.4	42	23.5	28.0	100.0	100.0	1.7
S	8.0	1	3.97	2.92	10.7	100	100.0	47.1	100.0	100.0	100.0
B	11.5	0	4.48	2.51	19.9	30	100.0	100.0	100.0	100.0	100.0
E	11.5	0	4.46	1.51	48.5	2	100.0	7.8	100.0	100.0	71.5
F	11.5	0	4.34	2.65	32.3	100	100.0	81.7	100.0	100.0	85.0
G	11.5	0	4.06	1.97	41.4	100	64.7	62.4	100.0	100.0	59.0
K	11.5	0	4.02	2.15	39.5	100	100.0	100.0	100.0	100.0	77.0
U	11.5	0	4.16	2.94	18.5	100	100.0	12.1	100.0	100.0	100.0
X	11.5	0	2.53	1.55	25.1	100	100.0	100.0	100.0	100.0	100.0

TABLE 40. RANK CORRELATIONS: COMPARISONS OF VARIOUS RANKING SCHEMES FOR TEXTILE STUDY DATA

	Expert ranking	
Bioassay	PLANTRNK	TOXIC
ECOL-PDOH	-.24	.30
HEALTH-PDOH	-.45	.54*
RAT	.14	-.18
FW ALGAL	.27	-.18
FW FISH	.78*	-.88*
DAPHNIA	.58*	-.48
SW FISH	.92*	-.81*
GRASS SHRIMP	.89*	-.81*
SW ALGAL	.47	-.48

NOTE: Numbers are correlation coefficients; asterisks indicate significance at the 0.05 level.

TABLE 41. STEPWISE REGRESSION ANALYSIS OF RANKING SCHEMES FOR TEXTILE STUDY DATA

	Order of bioassays selected	R^{2*} at each step
PLANTRNK	GRASS SHRIMP	.82
	FW FISH	.89
	HEALTH-PDOH	.92
TOXIC	FW FISH	.77
	SW FISH	.85

R^{2*} = Coefficient of determination (ratio of explained variation/total variation).

between the experts' rankings and freshwater fish, saltwater fish, and grass shrimp.

To further characterize these relationships, stepwise regression was run for PLANTRNK v. other ranking schemes and TOXIC v. other ranking schemes. Table 41 presents results of this analysis. It is noted that grass shrimp and saltwater fish are highly correlated, since only one of these two tests is selected each time in a stepwise regression. Three bioassays (freshwater fish, saltwater fish, and grass shrimp) predicted 92 percent of the variance in plant ranking by an expert panel and 85 percent of the variance if grouped rankings were considered.

SECTION 5

CONCLUSIONS

5.1 DISCUSSION

In discussions with IERL project officers and discussions at workshops and symposia on the environmental assessment program, a diversity of needs was noted, including:

1. A method for evaluating the overall multimedia effects of a control technology to support process/control developers and users in the most cost-effective manner.
2. A means of ranking sources for their overall severity or potential for environmental damage in order to more effectively support and direct research on controls.
3. A way to relate the results of the IERL environmental assessment program to the needs of various governmental regulatory agencies and laboratories to facilitate standards setting and enforcement.
4. The establishment of a data base characterizing the various waste streams or numerous industrial types to better support regulatory offices and the environmental sciences community.

There is an urgent need to determine where research efforts should be focused, and also a need to evaluate control devices for their overall efficiency. The Level 1 bioassays and the Level 1 chemistry, as interpreted through the SAM/IA model, are useful tools in answering these needs; the SAM/IA model, now in draft form, uses dispersion modeling to rank various effluents and emissions. Tables 28 and 29 in the previous section rank all samples from the four pilot studies by potential degree of hazard, based on chemical analysis for their relative hazards. These tables also show the various bioassay results as interpreted by the Litton grouping method. It is important to note here that each bioassay measures a unique biological effect; therefore, it is not appropriate to sum the results of a sample's bioassays to obtain a total "biologically based degree-of-hazard." For each effluent or emission, the bioassay results must be considered in light of the receptor ecosystem. When more data become available in an expanded data base, such factors as population density and pollutant dispersion should be included in a model dealing with environmental assessment data.

To best meet the needs of control technology evaluations and source rankings, the total multimedia effects should be considered. For example, if a mutagenic fly ash is efficiently removed from a gaseous emission by a newly developed control device, then a suitable method must be specified for disposing of, or rendering harmless, the fly ash collected by the control device (e.g., extraction and incineration of the extract). In supporting the developers and users of control technologies, the EA program should also consider the cost and feasibility of controls.

When all factors relevant to an intelligent decision on the acceptability of a waste stream--chemical test results, bioassay results, potential receptors, costs, and availability of controls--are considered, there appears to be no mathematical model now conceivable that will encompass all of them. The SAM models are useful for summarizing the many numbers generated by the environmental assessment chemical analysis, but the data on which the SAM's are based, the MEG/MATE values, must be constantly updated. When compared to the need, there is a paucity of information correlating results of the various environmental assessment bioassays with human health and other environmental effects outside of laboratory conditions. An enormous amount of information, an expanded data base, is being generated that should provide answers to many questions about the hazards of discharging industrial process waste streams into the environment and exposing humans to possible risks. Although there are similarities of chemical composition and biological effects with waste streams from comparable industries, the differences in geographical location make each industrial site and each waste stream a unique case. Although the environmental assessment program incorporates the state-of-the-art tests in these fields, expert judgment is needed to evaluate the results of an environmental assessment and to make decisions concerning applicable control technology. Therefore, it appears that the best means of answering the question of potential hazard would be the use of a multidisciplinary, expert panel composed of members knowledgeable in human health effects, other ecological effects, chemical hazards, control technology developments, socioeconomic factors, and statistics. It is proposed that the expert panel be composed of the environmental assessment EPA Project Officer, a representative of the primary contracting group, a member of the IERL Process Measurements Branch, and at least one specialist in each of the six disciplines mentioned above.

To meet the third and fourth needs mentioned in this evaluation--the support of standard setting and enforcement measures--it seems logical that the Level 2 and/or Level 3 environmental assessment efforts be identical to or easily correlated with the EPA reference and equivalent methods specified for standard setting and enforcement in the Federal Register and other officially and legally recognized publications. The philosophy of Level 2 is to include any pertinent Federal Register or other officially recognized standard methods as part of the Level 2 protocol; however, there very often are no standard (Federal Register) methods for pollutants of interest in Level 2 efforts. Level 1 of the environmental assessment scheme is designed as a comprehensive, cost-effective survey technique and, as such, could not easily be made compatible with the compound-specific Federal Register techniques for sampling and analysis. The Level 1 data, however, could be very valuable in assisting the regulatory agencies in focusing their initial efforts on the most hazardous sources, providing a description of the engineering and chemical processes involved at a source, and providing a broad base of information on both the chemical makeup and biological effects of waste streams at a source.

In a discussion of the interpretation of data from the IERL environmental assessment program, it should be mentioned that several earlier reports have dealt with this topic. An evaluation of the SASS train, executed and reported by the Mitre Corporation,[7] had as one goal a determination of correlations between the biological activity and the chemical composition of samples. Using the logarithm of concentration from analysis of SSMS or GC-MS data, the percent viability from the RAM cytotoxicity test results, and linear regression analysis, these investigators were unable to establish strong correlations between individual elemental concentrations and observed cytotoxicity in a given sample. It was suggested that this lack of strong correlation might be due to a lack of information on the biological availability/chemical form of the various elements.

In another approach, each element was assigned a toxicity rating from 1 (least toxic) to 10 (most toxic), based on most probable chemical form and most comparable exposure route. A chemical toxicity index was calculated by multiplying the toxicity rating by the concentration using SSMS or GC-MS analysis. Using linear regression analysis, the common logarithm of the chemical toxicity index was compared with the percent viability in the RAM test at maximum dosage (1,000 µg/mL). It was found that 20 elements (Sb, As, Be, Bi, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, Se, Ag, Te, Tl, Sn, Ti, V, and Zn) were most influential in predicting the toxicity of a given particulate sample. This method of analysis of the data assumes linear relationships and does not account for synergistic or antagonistic effects.

In her presentation at a recent symposium on bioassays, Dr. Judi Harris of Arthur D. Little, Inc., also examined the relationship between chemical and biological data in a paper entitled "Comparison of Chemical and Biological Data in Level 1 Environmental Assessments."[21] In her paper, she suggested the following:

> The uniformly positive response obtained in the initial Level 1 bioassays would imply that further biological testing of this sample/source is warranted. In determining the appropriate direction of Level 2 biotests, it is constructive to compare the Level 1 results of bioassays with those of the chemical analysis, even though no cause-effect correlation could be made on the basis of the available Level 1 data. The chemical analysis showed the presence of a variety of different classes of organic compounds, each of which contains at least some individual species known or suspected to be biologically active. It seems quite plausible to hypothesize that the variety of cytotoxic and mutagenic activities found in Level 1 bioassay of the whole sample, are, in fact, attributable to different chemical components of the sample.
>
> Comparison of the Level 1 chemical and biological data therefore provides valuable direction for the Level 2 studies. Monitoring of chemically fractionated samples in Level 2 by the most sensitive bioassay might lead to separability of the cytotoxic and mutagenic effects of the material.
>
> Other probably useful confirmatory biotests, on either whole or fractionated samples, might include:
> Other mutagenicity tests in microbial and mammalian cells
> In-vitro transformation systems
> Teratogenicity and/or chromosome damage analyses

5.2 RECOMMENDATIONS

The following suggestions are made as a result of a thorough examination of the data from the environmental assessment programs to date. It is understood that some of the proposed changes or additions may already be in the process of being implemented.

1. A uniform protocol for both chemical and biological analysis of sample types (solids, liquids, gases) should be implemented throughout the IERL. Such a protocol would allow for better statistical evaluation of results by ensuring a complete and consistent data set on each sample and eliminating missing values. It is essential that complete sets of information be obtained on each type of sample for a viable data interpretation model to be developed. Table 42 shows a sampling protocol[22] that IERL has proposed for use in environmental assessment projects. The SAM model series assumes that such a uniform protocol (including standard number of analyses) has been followed; the SAM/I and SAM/IA models total the ratio of each chemical's measured concentration to its MEG or MATE value. If more chemical analyses have been done on one sample than on another, it is likely that the sum of ratios (the PDOH value) would be greater for the first sample than the second, even though the second might have the same or greater potential hazard value.

   Sampling and analysis procedures should also be made uniform. In the pilot studies, different leaching procedures were used to generate samples from bulk solids for chemical analysis and for bioassay, so it was impossible to tell whether the chemical and biological systems were measuring solutions of similar or different compositions. The revised Level 1 manual[1] specifies a suitable aqueous leaching procedure that should be used with all chemical and biological tests on leachable materials.

2. More validation studies for Level 1 of the environmental assessment program should be planned and executed using the proposed uniform sampling protocol. These studies would increase the size of the available data base and they could be performed using the revised Level 1 procedures. In the pilot studies, some replicate samples should be

TABLE 42. GUIDELINES FOR BIOASSAY TESTING

Sample	Mutagenicity	Cytotoxicity	Whole animal	Aquatic	Plant	Soil
Liquids	A	A	A	A		C
Solids	A	A	A	A		C
Solids leachates	A	B	B	B		C
SASS particulate	A*	A*				
SASS organics	A*	A*				
Gases					C	

A Required test.

B Required when solid handling or use may result in water runoff.

C Terrestrial ecological tests (stress ethylene and soil microcosm) are in a developmental stage. Their use is recommended; however, they are not required on a laboratory-wide basis at this time.

*Additional SASS samples (1-2 extra runs) may be necessary to acquire adequate quantity of sample for biological tests.

analyzed so that a determination of variability can be made. The precision of analytical methods can also be determined by interlaboratory testing programs.

3. The continuation of basic research into cause-effect relationships should be supported to expand the MEG/MATE list. This information is essential to the determination of hazardous effects for which suitable bioassays have not been developed. For example, there is no Level 1 bioassay that will react to the mutagenic potential of beryllium. Therefore, the chemistry and biology analyses need to be run simultaneously and the basic knowledge on the biological effects of pure compounds needs to be well defined.

4. The terrestrial tests need further development with an emphasis on the interpretation of results. Even though these tests (soil microcosm and stress ethylene) yield much information, a clearly defined relationship is needed between terrestrial bioassay results and potential hazardousness of the sample; this is especially important in the soil microcosm test where response values at increasing dosages may increase, then decrease, for the same sample. In addition, the available data from the terrestrial bioassays show such a large degree of background variability that low toxic effects may not be detected. Measures need to be implemented to reduce the differences among both replicate samples and replicate controls; that is, to reduce the background. Work is currently underway to evaluate and incorporate revised soil and plant stress ethylene tests and a new insect test into the terrestrial bioassay group.

5. To ensure the completeness of the historical record of test results from an environmental assessment, it is recommended that the IR and LRMS spectra be included as an appendix to the Environmental Assessment Report. These spectra could be a valuable record in later checks for the presence or absence of some currently unidentified compound. The spectra would also aid in the interpretation of organic results and classification of weights of organics into MEG categories: If an LRMS spectrum is not available for a given fraction, the Level 1 manual suggests that the weight of materials in that fraction be assigned as they were in the adjacent fraction with the most similar spectrum.

6. A scale needs to be developed for quantifying responses other than lethality in the rodent acute toxicity test. For the group of samples considered in this study, it was impossible to discriminate or rank samples based on LD_{50} values because there were no lethal effects. However, various physiological and behavioral effects were observed in the samples. In an attempt to correlate the sublethal effects with chemical concentrations, the number of sublethal effects was simply totaled, with all effects considered of equal importance. The Level 1 bioassay manual[2] lists various possible sublethal effects; numerical weights could be assigned to these effects by experts in the field of whole animal toxicity.
7. In some test results from the aquatic ecological series, response values were reported as EC_{50} (concentration, expressed as percent sample in an aqueous diluent, affecting 50 percent of the population) or as LD_{50} (dose, expressed as percent sample in an aqueous diluent, that is lethal to 50 percent of the population). An examination of the raw data showed, in many cases, that a significant response occurred only at a level affecting less than 50 percent of the population, so EC_{50} values could not be computed for these samples. In order to show the numerical differences in the magnitude of responses, some values were computed as EC_{20} (concentration affecting 20 percent of the population). Realizing this variation exists, it is suggested that data collection and summary forms for the aquatic ecological series include entry spaces for EC_{20}, EC_{50}, and EC_{80} values (or LD_{20}, LD_{50}, and LD_{80}, if appropriate for the sample set), with the stipulation that all values be computed. This computation can be performed by a variety of readily available methods, such as the SAS PROBIT program[12] or graphical interpolation.
8. A number of those with whom this study was discussed expressed concern about the use of the Ames test on complex mixtures. Almost all of the validation and sensitivity studies correlating the Ames test with whole animal tumor studies have involved pure compounds. Although all types of complex mixtures found in environmental samples could not be validated through whole animal testing, some representative samples (e.g.,

automobile exhaust, fly ash from various coal-to-energy technologies) might be tested as both whole and fractionated samples in the Ames system and in the whole animal system.

9. One of the important types of information sought in an environmental assessment study is the effect on human health of various industrial waste streams. If pertinent epidemiological or other data are available, they should be assembled and studied; such data have been amassed for coking operations and for asbestos-handling operations.
10. Decision criteria for proceeding from Level 1 to Level 2 should be based on all data, the bioassay results as well as the chemistry. At a recent meeting, the Bioassay Subcommittee of the Environmental Assessment Steering Committee suggested that the following criteria be used for bioassays:
    a. Proceed to Level 2 if Level 1 samples show a mutagenic response in the Ames test.
    b. Proceed to Level 2 if Level 1 bioassay, other than the Ames test, shows a trend toward a toxic response. A significant positive response in more than one bioassay was suggested as indicating a trend in toxicity for the sample in question.

When the PDOH values and the bioassays are compared, PDOH values greater than ~1,000 for either health-related or ecology-related calculations correspond with a trend toward toxic responses in the bioassays; more data are needed to further define the significance of the PDOH value limits. An indication of the presence of a significant quantity of any known carcinogen or any known severe acute toxin, as shown by Level 1 chemistry, would certainly dictate proceeding to Level 2 validation chemistry.

REFERENCES

1. D. E. Lentzen, D. E. Wagoner, E. D. Estes, and W. F. Gutknecht, *IERL-RTP Procedures Manual: Level 1 Environmental Assessment* (Second Edition), EPA-600/7-78-201, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1978.

2. K. M. Duke, M. E. Davis, and A. J. Dennis, *IERL-RTP Procedures Manual: Level 1 Environmental Assessment Biological Tests for Pilot Studies*, EPA-600/7-77-043, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1977.

3. N. H. Gaskins and F. W. Sexton, *Compilation of Level 1 Environmental Assessment Data*, EPA-600/2-78-211, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1978.

4. J. M. Allen, J. E. Howes, Jr., S. E. Miller, and K. M. Duke, *Comprehensive Analysis of Emissions from Exxon Fluidized-Bed Combustion Miniplant Unit*, Draft Report, September 9, 1977, EPA Project Officer D. B. Henschel, U.S. Environmental Protection Agency, Research Triangle Park, NC.

5. G. C. Page, *Environmental Assessment: Source Test and Evaluation Report--Chapman Low-Btu Gasification*, EPA-600/7-78-202, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1978.

6. G. D. Rawlings, *Source Assessment: Textile Plant Wastewater Toxics Study*, Draft Report, December 1977, EPA Project Officer Max Samfield, U.S. Environmental Protection Agency, Research Triangle Park, NC. (Now available as EPA-600/2-78-004h from the U.S. Environmental Protection Agency, Research Triangle Park, NC.)

7. H. Mahar, *Evaluation of Selected Methods for Chemical and Biological Testing of Industrial Particulate Emissions*, EPA-600/2-76-137, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1976.

8. J. W. Hamersma, S. L. Reynolds, and R. F. Maddalone, *IERL-RTP Procedures Manual: Level 1 Environmental Assessment*, EPA-600/2-76-160a, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1976.

9. M. P. Schrag, A. K. Rao, G. S. McMahon, and G. L. Johnson, *Fine Particle Emissions Information System Reference Manual*, EPA-600/2-76-173, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1976.

10. M. P. Schrag, A. K. Rao, G. S. McMahon, and G. L. Johnson, *Fine Particle Emissions Information System User Guide*, EPA-600/2-76-172, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1976.

11. D. Brusick and R. Hart, internal communication, Litton Bionetics, August 1978.

12. A. J. Barr, J. H. Goodnight, J. P. Sall, and J. T. Helwig, A User's Guide to SAS 76, SAS Institute, February 1977.

13. D. J. Finney, Probit Analysis, 2nd ed., Cambridge: Cambridge University Press, 1952.

14. J. G. Cleland and G. L. Kingsbury, Multimedia Environmental Goals and Environmental Assessment, Volume 1, EPA-600/7-77-136a, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1977.

15. J. G. Cleland and G. L. Kingsbury, Multimedia Environmental Goals and Environmental Assessment, Volume 2, EPA-600/7-77-136b, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1977.

16. Environmental Protection Agency, Emissions Assessment of Conventional Combustion Systems, Vol. 1: Gas-Fired and Oil-Fired Residential Heating System Source Categories (Draft), EPA Contract 68-02-2197, Project Officer Dr. Ronald A. Venezia, U.S. Environmental Protection Agency, Research Triangle Park, NC. (Now available as EPA-600/7-79-029b from the U.S. Environmental Protection Agency, Research Triangle Park, NC.).

17. L. M. Schalit and K. J. Wolfe, SAM/IA: A Rapid Screening Method for Environmental Assessment of Fossil Energy Process Effluents, EPA-600/7-78-015, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1978.

18. M. A. Herther, L. R. Waterland, and R. J. Milligan, SAM 1B: A Rapid Screening Method Incorporating Biological Hazard Evaluation for Environmental Assessment of Fossil Energy Process Effluents (Draft), EPA Project Officer J. S. Bowen, U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1978.

19. L. A. Anderson, M. A. Herther, and R. J. Milligan, SAM I: An Intermediate Screening Method for Environmental Assessment of Fossil Energy Process Effluents, Acurex Report TR-79-154, EPA Project Officer, J. S. Bowen, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1978.

20. B. Ames, J. McCann, and E. Yamasaki, Methods for Detecting Carcinogens and Mutagens with the Salmonella/Mammalian-Microsome Mutagenicity Test, Mutation Res., 31:347-364, 1975.

21. M. D. Waters, S. Nesnow, J. L. Huisingh, S. S. Sandhu, and L. Claxton, Application of Short-term Bioassays in the Fractionation and Analysis of Complex Environmental Mixtures, EPA-600/9-78-027, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1978.

22. J. A. Dorsey, internal communication with J. K. Burchard, August 1978.

APPENDIX A

THE DATA BASE

The 51 Fortran-encoded sample sets are presented as they were numbered in this study. These sample sets include all appropriate chemical and biological testing results from the four studies described in this document. Table 4 in the text of the document shows the location of parameters on these data printouts. Table 5 in the text indicates the unit of measure in which each parameter is expressed. Negative signs preceding data identify results that were less than the minimum detectable limit of the analytical procedure; in such cases a value equal to half the minimum detectable limit was entered. See subsection 3.1.1.

DATA BASE FOR STUDY 06

```
010602SEPARATAR       2.6
020602      3.5       1.7     0.182     0.165        4.
030602`
040602
050602
060602       0.        0.        5.       50.        0.        0.        0.
070602       0.        0.        0.        0.        0.        0.        0.
080602       0.        0.        0.        0.        0.        0.        0.
090602       0.        0.        0.        0.        0.        5.        5.
100602       3.        0.        5.        0.       80.        0.        0.
110602      2.5        0.        0.        0.        0.        0.        5.
120602       0.        1.       20.       0.5                0.03       -.1
130602       0.        9.        0.      300.        0.        0.        0.
140602       0.       10.       0.5        0.      -.25        0.     7000.
150602              2000.        0.        0.        0.       50.        0.
160602                 1.        0.        0.      100.       40.        0.
170602       0.        0.        0.        0.       40.        0.       60.
180602       0.        0.        0.        0.       40.        0.        0.
190602      80.        0.        0.      300.        0.      200.      100.
200602     100.        0.        0.        0.
210602                        1490.    10950.    96800.    47000.    41030.
220602  293370.    27880.    41630.
230602                                   0.06
240602
250602
260602
270602
280602      1.2       2.0       2.2      17.5       1.5      23.9       1.4
290602      4.8       1.5      33.9
300602       4.        2.
310602
010603SEPARALIQ        0.
020603       0.        0.     0.359                  1.       10.        0.
030603                0.5       1.9        0.       .03       .02      0.51
040603     0.11       .23       .20       .16       .41       .41       .25
050603     23.2
060603       0.        0.        0.        0.        0.        0.        0.
070603       0.        0.        0.        0.       10.        0.        0.
080603       0.        0.        0.        0.        0.        0.        0.
090603       0.        0.        0.        0.        0.        3.        7.
100603     300.        1.      300.        0.       70.       30.        0.
110603       5.        2.        0.        0.        0.        0.        8.
120603      10.        5.       80.       10.      300.     2000.      800.
130603       0.        0.        0.       10.        0.        0.        0.
140603    1000.        0.        0.      100.        2.    20000.    20000.
150603              8000.    20000.     2000.               2000.        0.
160603              9000.        0.        3.       30.        0.        0.
170603       0.        0.      100.        0.      100.        0.        0.
180603       0.        0.      500.        0.        0.        0.        0.
190603     300.        0.        0.      100.        0.      500.        0.
```

STUDY 06 (continued)

```
200603             50.         0.        0.3       0.02
210603             0.2
220603
230603                                               -0.                                 1.
240603
250603            0.10
260603
270603           5000.      1000.       0.07
280603             1.1        1.1        3.0        1.5        0.9        1.4        1.1
290603             1.0        1.4        1.2
300603              1.         3.         3.                    1.
310603
010604GASIFLASH             98.7
020604            87.9      109.4         0.         0.         1.        10.         0.
030604
040604
050604            19.7
060604            400.         0.         0.        20.         0.         0.         0.
070604              0.         0.         0.         0.         0.         0.         0.
080604              0.         0.         0.         0.         0.         0.         0.
090604              0.         0.         0.         0.         0.        90.       100.
100604           2000.         0.         0.         0.       200.       300.         0.
110604            -4.5         0.         0.         0.         0.         0.        20.
120604             90.       -10.      2000.     20000.         0.        30.        -.2
130604              0.        50.         0.      1000.         0.        50.     10000.
140604              0.        30.        30.      3000.        50.     50000.     10000.
150604                       600.       800.      7000.      3000.      6000.         0.
160604                        20.     10000.        70.         0.         0.         0.
170604              0.         0.         0.         0.         0.         0.         0.
180604              0.         0.         0.         0.         0.         0.         0.
190604              0.         0.         0.         0.         0.         0.         0.
200604              0.         0.         0.        -0.
210604
220604
230604                                              -.15
240604
250604
260604
270604
280604             1.2        1.4        1.8        1.1        1.3        1.1        1.2
290604             1.1        1.5        1.0
300604              1.         1.                               1.
310604
010605CYCLODUST             94.9
020605            89.2      100.5         0.         0.         1.        10.        33.
030605
040605
050605             17.
060605              0.         0.         0.        60.         0.         0.         0.
070605              0.         0.         0.         0.         0.         0.         0.
```

STUDY 06 (continued)

080605	0.	0.	0.	0.	0.	0.	0.
090605	0.	0.	0.	0.	0.	20.	20.
100605	500.	0.	0.	0.	100.	0.	0.
110605	0.	0.	0.	0.	0.	0.	0.
120605	30.	10.	80.	3.	0.	0.	-.2
130605	0.	-5.	0.	900.	100.	3.	1000.
140605	200.	30.	20.	200.	2.	2000.	1000.
150605		300.	8000.	2000.	100.	500.	0.
160605		7.	0.	2.	0.	0.	0.
170605	0.	0.	0.	0.	0.	0.	0.
180605	0.	0.	0.	0.	0.	0.	0.
190605	0.	0.	0.	0.	0.	0.	0.
200605	0.	0.		0.			
210605			109.	18.	1.	3.	3.
220605	113.	19.	44.				
230605							
240605							
250605							
260605							
270605							
280605	0.9	1.9	1.6	1.1	1.4	0.8	1.1
290605	1.1	1.2	1.1				
300605	1.	1.			1.		
310605							

DATA BASE FOR STUDY 10

```
011009BED LEACH      84.0
021009     99.4      68.5        0.     0.122
031009                30.                31.8      25.3                42.3
041009     40.9      100.      100.      100.      100.      100.      100.
051009
061009   -3000.    -3000.     -500.    15000.    -2000.    -2500.    -2500.
071009   -2500.    -1000.    -2500.    -1000.     5000.   -50000.    -2000.
081009    -500.    -2000.     -500.    -2000.     -500.    -2000.     -500.
091009   -2000.    -2000.    -3000.    -1000.     -500.     -500.    70000.
101009  500000.     7000.      600.    -2000.     -350.   100000.    -1000.
111009   -1000.     -500.    -1000.    -1000.    -7500.    70000.     -300.
121009    3000.     -300.   700000.   150000.    70000.    15000.   150000.
131009   -2000.     3000.   -50000.    30000.   300000.    -5000.  2000000.
141009   10000.    30000.     5000.   300000.    -1500.500000000. 10000000.
15100920000000.150000000.   150000.   400000.   150000.   200000.  2000000.
161009   -2000.   200000.      -30.   200000.
171009
181009
191009
201009                        64000.     2100.   200000.     -150.      800.
211009
221009
231009                                    -2.5      -10.       50.
241009
251009
261009                                          1500000.
271009
281009
291009
301009                 1.                            1.        2.        1.
311009       2.        2.        1.
011008BEDREJECT      56.6
021008     61.2      52.0                            1.
031008
041008
051008
061008       .2        1.      -.05        1.        2.      -.15      -.05
071008     -.15       -.1      -.15       -.1      -.15       -.5      -.15
081008     -.05      -.15      -.05      -.15      -.05        .6        .5
091008       1.        .5       1.5        4.        .5       20.        6.
101008     100.        2.     -.035      -.15        .4        1.       -.3
111008     -.25      -.05      -.05       -.2       -.5        4.       1.5
121008      20.        5.      300.       40.        1.       1.5       15.
131008       7.       15.        5.       15.      150.        2.    30000.
141008     100.       30.       30.      400.        3.   150000.    20000.
151008      40.    15000.      100.    70000.    50000.   100000.       50.
161008       .3      100.        1.      100.        0.        0.        0.
171008       0.        0.        0.        0.        0.        0.        0.
181008       0.        0.        0.        0.        0.        0.        0.
191008       0.        0.        0.        0.        0.        0.        0.
```

STUDY 10 (continued)

```
201008       0.        0.      .025       .01      26.1      .002    -.0005
211008      8.7      .005        0.        0.        0.        0.        0.
221008       0.        0.        0.        0.        0.        0.        0.
231008       0.        0.        0.      -.01        2.       35.
241008
251008
261008                                                60.
271008
281008      1.1       1.3       1.2       1.0       1.1       1.2       1.3
291008      1.0       1.5       1.5
301008       1.        1.                            1.
311008
011007CYCLOLEACH     67.6
021007     77.3      57.9     0.092     0.128
031007                11.                100.      100.      100.      100.
041007     91.6      100.      100.      100.       75.       75.      72.5
051007
061007   -1500.    -1500.     -250.     7000.     -500.    -1000.    -1000.
071007   -1000.     -500.    -1000.     -500.     1500.    -7500.    -1000.
081007    -250.     -100.     -250.    -1000.     -250.    -1000.     -250.
091007   -1000.    -1000.    -1500.     1000.     -250.     1000.    10000.
101007  100000.    20000.     2000.    -1000.     -150.     3000.     -500.
111007    -500.      500.     -500.     -500.    -1500.    30000.     -150.
121007    3000.     -150.   300000.   300000.     7000.    20000.    15000.
131007   -1000.     2000.     -250.    50000.    30000.    -2500.   200000.
141007   -2500.    50000.    20000.   150000.500000000.150000000.   300000.
15100770000000.   250000.  5000000.   700000.  1500000. 15000000.     2500.
161007  100000.      -15.  1000000.
171007
181007
191007
201007                      53000.      400.   200000.     -150.    49000.
211007
221007
231007                                  -2.5      -10.       50.
241007
251007
261007                                       1500000.
271007
281007
291007
301007                 1.                            1.        2.        2.
311007       1.        1.        1.
011006CYCLODUST      69.9
021006     81.7      58.1     0.138     0.124        1.
031006
041006
051006
061006       2.        4.        .3       20.       1.5       -.2      -.05
071006      -.2       -.1       -.2       -.1      -.25       -.5       -1.
```

STUDY 10 (continued)

```
081006         .3         3.        .3         2.        .6         4.        .7
091006         5.         2.        7.        40.        7.       100.       50.
101006       600.        10.        .1         .6        .7         3.       -.3
111006        1.5        -.1       -1.        -.2       -.5         3.        5.
121006       100.        15.      700.       150.        5.        1.5       10.
131006         6.        20.       40.        50.      100.        10.   100000.
141006       100.        50.      100.      5000.       15.     50000.     3000.
151006        10.      7000.      300.     30000.    60000.     30000.     1500.
161006         6.        30.       .15       100.      .017       .001      .013
171006         0.       .002      .004       .015      .012       .004      .002
181006         0.         0.      .001       .001      .001       .001      .004
191006       .002         0.        0.      .0005     .0005       .004      .004
201006       .004       .004       .03       .017      14.2     -.0005      .006
211006        2.3       .003        0.        12.        0.        22.       23.
221006         0.         0.        0.        15.       19.        10.        3.
231006         4.         3.        3.        .05        2.        33.
241006
251006
261006                                                 140.
271006
281006        1.1        1.0       1.2        0.8       1.1        0.8       1.3
291006        0.8        0.8       0.8
301006         1.         1.                             1.
311006
011004CORSEPART         64.5
021004       73.0        56.                             3.
031004
041004
051004
061004         2.         7.        .7        60.        4.        -.2      -.05
071004        -.2        -.1       -.2        -.1        1.        -1.        3.
081004         .4         3.        .5         3.        1.         7.        1.
091004         6.         3.        7.        40.       15.        70.       30.
101004      1000.        20.      -.05       -.15        1.         3.      -.05
111004        -3.         1.       -1.        -.1      -.05        10.       10.
121004       300.        50.     1500.       300.        7.        10.       50.
131004        10.       100.      100.        70.      400.        30.    60000.
141004       200.       300.      100.      7000.       50.     50000.    50000.
151004         7.     20000.      500.    150000.   200000.     20000.     2000.
161004        15.       100.        4.       300.      .002       .005      .004
171004         0.       .004      .004       .008      .012       .004      .004
181004         0.         0.      .002       .002      .007       .007      .004
191004       .004         0.        0.       .004      .004       .004      .004
201004       .004       .004      .005       .032      10.1       .003    -.0005
211004        -.1      -.015       16.        27.       44.         0.        0.
221004         0.         0.        0.        69.        4.        12.        0.
231004         0.         0.        1.       -.01       3.3        64.
241004
251004
261004                                                  30.
```

STUDY 10 (continued)

```
271004
281004         0.8         1.3         2.6         1.6         4.2         2.1         1.3
291004         0.8         3.9         1.5
301004          2.          1.
311004
011003FINE PART           47.5
021003        58.3        36.8       0.141       0.156          4.
031003
041003
051003
061003          7.         15.          .4        100.          4.         -.2        -.05
071003         -.2         -.1         -.2         -.1          1.         -1.          3.
081003          .4          6.         0.3          3.          1.          5.          1.
091003          6.          3.          7.         40.         10.         70.         30.
101003       2000.         40.          .4        -.15          1.          3.         -.3
111003        -1.5          1.         -1.         -.1         -.5          5.          5.
121003        100.         30.        700.        600.          4.         10.         40.
131003         10.         70.        100.         40.        200.          0.      30000.
141003        200.        200.        200.       4000.         20.      30000.      15000.
151003          4.       4000.        300.     100000.     100000.      20000.       2000.
161003         15.        100.          4.        500.         .38         .13        .003
171003          0.          0.        .003        .003          .0        .003          0.
181003          0.          0.          0.          0.          .1          .1        .003
191003          0.          0.          0.         .05         .05        .003
201003        .053        .003        .003        .032        10.8        .001      -.0005
211003         -.1       -.015        767.        494.        461.         28.          0.
221003          0.          0.        562.        659.       1038.        266.         65.
231003        118.         88.         81.         .16         5.3         85.
241003
251003
261003                                                        20.
271003
281003         1.8         1.5         1.5         1.1         2.6         1.4         1.6
291003         1.1         6.9         2.7
301003          2.          2.
311003
011002 DOLOMITE           97.1
021002       101.8         95.                                  1.
031002
041002
051002
061002          .3          3.       -.075         1.1         -.1         -.2        -.05
071002         -.2         -.1         -.2         -.1         -.2         -1.        -.15
081002        -.05        -.15        -.05        -.15        -.05        -.15        -.05
091002        -.15       -.075        -.25        -.25        0.15          .5          .4
101002          4.       -.268       -.035         -.1       -.125         -.1        -.15
111002        -.25        -.05         -.1        -.05         -.3        -.75       -.048
121002         .45          .3         40.         4.5         4.5         .45         13.
131002         .45          .2         3.5        2.25         70.        -.05        800.
141002         75.          5.         1.5         25.        -.15     225000.       5000.
```

STUDY 10 (continued)

```
151002     235.      300.        2.     1500.      650.   175000.      750.
161002      10.       10.     .0125      12.5
171002
181002
191002
201002                         .052     -.006        .6    -.0005    -.0012
211002     63.4      .068
221002
231002
241002
251002
261002                                              30.
271002
281002      1.7       1.1       1.5       2.6       1.0       1.3       1.3
291002      1.0       1.3       0.8
301002       1.        1.                            1.
311002
011001FEEDCOAL        71.
021001     72.8      69.2                            1.
031001
041001
051001
061001       .6        5.      -.01        28     -.045       -.1      -.01
071001     -.03     -.015      -.03     -.015      -.75      -1.5        1.
081001     -.15        .2     -.015       .15       .04        .3     -.032
091001       .1       .08        .8        1.        .5        8.        4.
101001     180.        .5     -.015     -.015       1.5       .15      -.05
111001      .05       .03     -.015     -.015      -.03        2.        .2
121001      4.5       0.5       19.       21.       16.       4.5        8.
131001       .3        3.       32.       16.       11.       4.5     6400.
141001      6.5       30.       16.      600.       1.5     1500.     2000.
151001    1335.     2000.       32.    48000.    17000.     3520.      200.
161001       .2        5.        .1        8.       .11       .02      .014
171001        0      .434      .014      .228      .462      .014      .084
181001        0         0      .042      .122       .14       .03      .044
191001     .214         0         0       .05       .05      .094       .03
201001     .014      .094       .49      .011       .03    -.0005   -.00075
211001      .10     1.065     121.5       95.     187.5       93.      42.5
221001    320.5     542.5        0.     345.5     349.5     191.5       65.
231001      94.      76.5     313.5
241001
251001
261001
271001
281001      1.3       1.0       1.0       1.2       1.3       1.3       1.2
291001      1.2       2.0       0.8
301001       1.        1.                            1.
311001
```

DATA BASE FOR STUDY 15

```
011501STEEL3MIC
021501      60.3
031501
041501
051501
061501       .33      -.115        11.       900.        .53       -.05       -.05
071501      -.05       -.05       -.05                   11.        .82       -.05
081501      -.05       -.05       -.05       -.05       -.05       -.05       -.05
091501      -.05       -.05       -.05        .68        .13        1.2        .21
101501       6.3        .26        1.7        .15        27.       340.
111501       5.4        41.       -.05       -.05       -.05        35.        .93
121501       .64        .78        4.8        32.        10.        2.7       190.
131501       7.1        90.     20000.      3600.       490.       120.    400000.
141501     5200.       880.       290.        33.       -.08     20000.      6900.
151501      270.     20000.      5000.      8900.        68.     10000.     20000.
161501      790.        47.       -.12        59.
171501
181501
191501
201501
211501
221501
231501
241501
251501
261501
271501
281501
291501
301501
311501
011502STEEL1MIC
021502      65.3
031502
041502
051502
061502       1.5       -.11        21.      1900.        1.5       -.05       -.05
071502      -.05       -.05       -.05                   10.        .79       -.05
081502      -.05       -.05       -.05       -.05       -.05       -.05       -.05
091502      -.05       -.05       -.05        .65        .13        1.1       .20
101502       12.        2.5        3.9        .40        70.       610.
111502       44.        65.       -.05       -.05       -.05        79.        0.9
121502       1.4        .51        11.        95.        43.        2.3       480.
131502       18.        87.     20000.      2900.       470.       110.    400000.
141502     4400.        60.       330.        15.       -.08      8300.     30000.
15150       260.     40000.      4900.      4300.       140.     10000.     80000.
161502      760.        31.        .34       110.
171502
181502
191502
```

STUDY 15 (continued)

```
201502
211502
221502
231502
241502
251502
261502
271502
281502
291502
301502
311502
011503COKE1MICR
021503      73.2
031503
041503
051503
061503       3.4         .24         48.        940.         7.5        -.05        -.05
071503      -.05        -.05        -.05                     .87         .18        -.05
081503      -.05        -.05        -.05        -.05        -.05        -.05        -.05
091503      -.05        -.05        -.05        -.05        -.05         .10         .03
101503       1.0         .53         1.8         .85         3.7         66.
111503       9.4         4.2        -.05        -.05        -.05         17.        -.05
121503       .66         .08         1.2         21.         1.1         9.8         3.9
131503       .98         4.0       1100.        170.         51.         2.6      10000.
141503      250.         94.         38.         8.0      10000.       1100.       1700.
151503       17.      10000.         41.        200.         5.3        170.       2200.
161503      220.         3.3         .25         6.1
171503
181503
191503
201503
211503
221503
231503
241503
251503
261503
271503
281503
291503
301503
311503
011504STEEL03MI
021504      85.9
031504
041504
051504
061504       6.2      -0.125         5.0        170.         .78        -.05        -.05
071504      -.05        -.05        -.05                     12.         .44        -.05
```

STUDY 15 (continued)

```
081504     -.05      -.05      -.05      -.05      -.05      -.05      -.05
091504     -.05      -.05      -.05       .73      0.15       5.9       2.2
101504      68.       2.8       19.       .15       17.      140.
111504      9.7      440.      -.05      -.05      -.05       38.       2.3
121504      .69       .56       43.       63.      110.       .51       67.
131504      10.       97.     5800.     1100.       93.      130.   800000.
141504   10000.      220.       40.       .44      -.09    40000.    40000.
151504   30000.     3500.     3500.    10000.       73.    20000.    90000.
161504   50000.      130.      -.13       27.
171504
181504
191504
201504
211504
221504
231504
241504
251504
261504
271504
281504
291504
301504
311504
011505STEEL01MI
021505     90.0
031505
041505
051505
061505     -.07      -.07       2.9      210.       .97      -.05      -.05
071505     -.05      -.05      -.05                 6.8       .52      -.05
081505     -.05      -.05      -.05      -.05      -.05      -.05      -.05
091505     -.05      -.05      -.05       .18       .04       .73       .28
101505      40.       1.2       2.6      -.04       9.7       40.
111505      12.       43.      -.05      -.05      -.05       10.       2.7
121505      .40       .71       14.       74.       65.       .40       52.
131505      6.0       57.     4600.      800.       46.       57.   400000.
141505    7700.      170.       23.       9.6      -.05    20000.    20000.
151505   30000.    50000.     1200.     5600.       21.     2500.      770.
161505   60000.       50.     -.075       16.
171505
181505
191505
201505
211505
221505
231505
241505
251505
261505
```

STUDY 15 (continued)

```
271505
281505
291505
301505
311505
0115061RUN3MICR
021506      111.4
031506
041506
051506
061506        2.3        2.3        5.7      2100.        11.       -.05       -.05
071506       -.05       -.05       -.05                   6.8        .29        .63
081506        .06        .57        .03        .53        .13        1.8        .10
091506        .41        .98        1.1        9.5        .95        38.        7.3
101506        60.        18.        29.        .58        2.5        4.4
111506        14.        6.1       -.05       -.05       -.05        11.        6.5
121506        10.        65.       160.       180.       150.        89.        35.
131506        2.9        6.3       760.      1000.        26.        86.     60000.
141506       640.        76.        48.       290.        1.1    400000.     10000.
151506      3300.      3100.      1300.     30000.      1300.     60000.     30000.
161506     10000.        61.        .57        18.
171506
181506
191506
201506
211506
221506
231506
241506
251506
261506
271506
281506
291506
301506
311506
0115071RUN1MICR
021507       46.0
031507
041507
051507
061507        3.7        3.7       100.      8200.        35.       -.05       -.05
071507       -.05       -.05       -.05                   3.6        .20        .44
081507        .24        .21        .09        .37        .09        1.3        .15
091507        .28        .67       -.05        6.5        2.8        46.        10.
101507       140.        25.        69.        2.0        3.5        6.1
111507        22.        35.       -.05       -.05       -.05        17.        4.5
121507        14.        25.       110.       950.       270.       310.       120.
131507        9.2        4.4      1100.      2200.        64.        59.     20000.
141507       321.        52.        33.       370.        1.1    300000.     30000.
```

STUDY 15 (continued)

```
151507   10000.    10000.      890.    20000.      890.    40000.    50000.
161507    7000.       76.       .39       28.
171507
181507
191507
201507
211507
221507
231507
241507
251507
261507
271507
281507
291507
301507
311507
01150801L1MICRO
021508     15.8
031508
041508
051508
061508      1.3       1.3       1.1      450.       .78      -.05      -.05
071508     -.05      -.05      -.05                 2.4       .41      -.05
081508     -.05      -.05      -.05      -.05      -.05       .31       .04
091508      .10       .33      -.05      0.68       .14       14.       .52
101508     280.       4.6       .61       .12       7.8       14.
111508      .97       4.4      -.05      -.05      -.05      814.       .22
121508      2.2       13.       57.       29.       10.       63.       9.3
131508      4.7      190.      900.      300.       5.2      220.    10000.
141508     220.     1000.    20000.      210.      -.04    10000.     3500.
151508      33.    70000.     1600.     4500.      3.40     5900.   200000.
161508      31.       16.       8.1       13.
171508
181508
191508
201508
211508
221508
231508
241508
251508
261508
271508
281508
291508
301508
311508
011509COPPER1MI
021509     38.0
```

STUDY 15 (continued)

```
031509
041509
051509        5.6          .56       20000.     350000.       3900.                    25.
061509       -.05         -.05        -.05        -.05         180.         1.3       -.05
071509       -.05         -.05        -.05        -.05         -.05        -.05       -.05
081509       -.05         -.05        -.05         9.8          2.0         3.9        4.1
091509       170.          1.9        160.       3600.       80000.      40000.
101509      4900.        1100.        -.05        -.05         -.05       5100.        31.
111509        11.          19.         29.        140.         750.       5500.     30000.
121509       140.          6.5      10000.      50000.        1300.        180.     30000.
131509       310.         190.         49.        560.          .78       7500.    100000.
141509       610.       20000.       1300.      10000.         250.      20000.     30000.
151509       210.          11.         5.9         43.
161509
171509
181509
191509
201509
211509
221509
231509
241509
251509
261509
271509
281509
291509
301509
311509
011510CUPPER3MI
021510       32.6
031510
041510
051510
061510        2.4          1.1      10000.      40000.        1100.                   -.05
071510       -.05         -.05        -.05                      13.         79.       -.05
081510       -.05         -.05        -.05        -.05         -.05        -.05       -.05
091510        .31         -.05         3.6         9.8          2.0         20.        7.9
101510        81.          3.7        160.       1300.       30000.       4600.
111510      1400.        2200.        -.05        -.05         -.05       2500.        6.7
121510        11.          8.1         82.         43.         750.       3400.        6.0
131510        24.          13.       7000.     200000.         760.        480.    200000.
141510       880.          79.         98.       1100.          1.7      40000.     10000.
151510      1100.       20000.       1300.      30000.        2500.      10000.     70000.
161510       370.          23.         59.         18.
171510
181510
191510
201510
211510
```

STUDY 15 (continued)

```
221510
231510
241510
251510
261510
271510
281510
291510
301510
311510
011511ALSM1MICR
021511     37.1
031511
041511
051511
061511      1.3      -.12      270.      330.       3.0      -.05      -.05
071511     -.05      -.05      -.05                 21.       1.5      -.05
081511     -.05      -.05      -.05      -.05      -.05      -.05      -.05
091511     -.05      -.05      -.05       1.1       .08       .45       .37
101511      5.2       7.5       34.       26.      130.      100.
111511      16.       2.0      -.05      -.05      -.05       67.       1.8
121511      5.3       2.2       9.4       98.       86.       22.     4100.
131511      3.4      900.      160.     2200.     2800.       43.    40000.
141511      20.       90.     5100.      130.     -.085     1800.     4100.
151511     690.    30000.     7600.      740.    20000.      330.    80000.
161511  500000.       72.       2.9       9.8
171511
181511
191511
201511
211511
221511
231511
241511
251511
261511
271511
281511
291511
301511
311511
011512ALSM3MICR
021512     52.4
031512
041512
051512
061512      .40      -.06       56.       78.       .19      -.05      -.05
071512     -.05      -.05      -.05                 20.       .91      -.05
081512     -.05      -.05      -.05      -.05      -.05      -.05      -.05
091512     -.05      -.05      -.05      -.05       .03       .14       .05
```

STUDY 15 (continued)

```
101512      25.         .27         16.         4.3         66.         33.
111512      1.8         1.1        -.05        -.05        -.05         51.         .48
121512      1.5         1.4         50.         6.1         23.         14.        700.
131512      2.1        200.         56.       4600.       3800.         27.      20000.
141512      6.3         56.       1500.        140.        -.04      20000.        840.
151512     140.       6000.       2000.        230.       3500.        870.         27.
161512  200000.         27.         1.8         13.
171512
181512
191512
201512
211512
221512
231512
241512
251512
261512
271512
281512
291512
301512
311512
011513CERAM1MIC
021513     54.1
031513
041513
051513
061513      10.         10.        140.         60.         10.        -.05        -.05
071513     -.05        -.05        -.05                     17.         .54         .99
081513      .32         1.1         .12         .50         .27         1.7         .36
091513      .89         1.3         2.5          45          13         180          37
101513     480.          6.         11.         2.7         10.         36.
111513      13.         .57        -.05        -.05        -.05         23.         29.
121513      35.         61.       1200.        460.         14.         42.        890.
131513      6.3         60.        360.        210.         88.         3.4      60000.
141513    1600.        150.        540.     510000.         15.     150000.      40000.
151513     330.       3800.     610000.     400000.      30000.     100000.     200000.
161513   90000.        100.         2.3        390.
171513
181513
191513
201513
211513
221513
231513
241513
251513
261513
271513
281513
```

STUDY 15 (continued)

```
291513
301513
311513
011514CERAM3MIC
021514     72.0
031514
041514
051514
061514      5.6       11.       79.       33.       5.3      -.05      -.05
071514     -.05      -.05      -.05                 3.7       .60       1.3
081514      .36       9.2       .14        1.        .3       4.5       .53
091514      .99       1.8       3.6        49       9.9      200.       27.
101514     290.       6.6       5.9       1.3       5.3       9.2
111514      6.6       .64      -.05      -.05      -.05       12.       32.
121514      38.       38.     1400.      370.       7.6       20.      110.
131514      1.4       36.      220.       93.       36.       18.    60000.
141514    1300.      120.      210.     6700.       40.   150000.    40000.
151514     200.     4700.     6700.   300000.    30000.    60000.   150000.
161514   10000.      230.       1.2      430.
171514
181514
191514
201514
211514
221514
231514
241514
251514
261514
271514
281514
291514
301514
311514
011515SLUDGE1MI
021515     43.2
031515
041515
051515
061515      11.       2.3     1500.     1300.       2.5      -.05       84.
071515     -.05      -.05      -.05                 35.       1.4       2.7
081515      .72       .29       .10       .26       .13       1.8       .21
091515      1.5       .97       1.1       47.       9.4      190.       39.
101515    1700.       18.      280.       .29       2.5    10000.
111515     660.      600.      -.05      -.05      -.05      110.       30.
121515     210.       18.     1300.       22.      720.       73.      100.
131515      2.8      130.     5600.    30000.     4500.      850.    70000.
141515     850.     4000.       94.     5300.       3.8    10000.    10000.
151515    4600.     8000.   100000.   100000.     9000.    60000.   100000.
161515    4300.       82.       2.4       50.
```

STUDY 15 (continued)

```
171515
181515
191515
201515
211515
221515
231515
241515
251515
261515
271515
281515
291515
301515
311515
011516SLUDGE3MI
021516     65.3
031516
041516
051516
061516      31.       3.1     1900.     2200.       5.3      -.05      120.
071516     -.05      -.05      -.05                 44.       3.4       3.7
081516      .37       .37       .08       .31       .13       2.5       .30
091516      .55       1.3       2.6       55.       11.      220.       42.
101516    2000.       11.      330.       .34       30.     5000.
111516     790.      500.       16.      -.05      -.05       33.       31.
121516     120.       21.     1500.       24.      420.       52.       43.
131516      1.7       74.     5600.    30000.     3000.     1000.    80000.
141516    1000.     2300.       55.     3800.       4.4   200000.     1000.
151516    2700.     5700.   100000.    80000.     6900.    70000.    80000.
161516    2500.       65.       14.       85.
171516
181516
191516
201516
211516
221516
231516
241516
251516
261516
271516
281516
291516
301516
311516
```

DATA BASE FOR STUDY 19

```
01190APLANT A
02190A                              0.      0.159         1.        10.        10.
03190A                 76.                                          19.
04190A        9.0      75.        69.5        62.       37.6        24.       21.2
05190A       26.2
06190A    -0.0015  -0.0015      -0.003        .38      -.002                 -.0005
07190A     -.0005   -.0005      -.0005                 -.004                  -.005
08190A      -.001   -.0035       -.001     -.0035     -.0005     -.0005      -.0005
09190A     -.0015    -.001       -.001      -.002       .009       .002        .004
10190A        .51     .003        .011     -.0005       .095        .10
11190A       .005     .001      -.0005     -.0005     -.0005       .043      -.0005
12190A       .031     .003         .70        .19        .47       .003      -.0075
13190A      -.005    -.005         13.        .14         1.       .021         6.1
14190A        .48      1.4         2.5       .087      -.003       170.         6.8
15190A        11.     130.          6.        18.        6.4        10.        180.
16190A        1.1               -.0015        .12    .001873               .0000398
17190A           .0000398                            .0000788
18190A                                               .001085
19190A   .0000788
20190A                                                .00085     .00019     .000006
21190A                           -.005       1.61        .53      -.005       -.005
22190A       1.02    -.005         2.1
23190A                                    -.00025        .03     -.0025
24190A
25190A                 7.3          0.       100.       168.      1652.         5.5
26190A      1500.    1725.        234.        .18        8.5         4.        63.7
27190A       12.8                             1.
28190A        1.7      1.5         1.0        1.1        1.2         .8         1.2
29190A        1.1
30190A         1.                                         1.                     3.
31190A         2.
01190BPLANT B
02190B                              0.      0.088         1.        10.          6.
03190B                 30.        100.                             100.
04190B       100.     100.        100.       100.       100.       100.        100.
05190B       19.9
06190B     -.0015   -.0015      -.0025        .17      -.001                 -.0005
07190B     -.0005   -.0005      -.0005                -.0035                 -.0045
08190B     -.0005    -.003       -.001     -.0015     -.0005     -.0005      -.0005
09190B     -.0015    -.001       -.001     -.0015      -.001     -.0015       -.001
10190B         .2     .001        .004     -.0005       .019       .017
11190B       .006     .001      -.0005     -.0005     -.0005     -.0035      -.0005
12190B       .004     .002         .22        .25        .26       .006         .28
13190B     -.0005   -.0005         1.2        .16       .017       .008         2.4
14190B        .41      .24        .005       .079     -.0015        21.         79.
15190B        2.1     300.         45.         8.        .69        14.        190.
16190B        3.7               -.0015       .032    .000934
17190B                         .000005               .000515
18190B
19190B     .00139
```

STUDY 19 (continued)

```
20190B                                                    .0368   .0000002-.00000025
21190B                              -.005       1.03      -.005        .38      -.005
22190B         1.39      -.005        1.5
23190B                                         .0006    -.00025     -.0025
24190B
25190B                    7.5          0.        5.5                   99.         7.
26190B        1200.     1681.          7.       .004                   20.       3.18
27190B          2.5                              7.3
28190B          1.6       1.2         1.6        1.0        1.2        1.0        1.1
29190B          1.1
30190B           1.                                          1.                    1.
31190B           1.
01190CPLANT C
02190C                              0.169      0.163         1.        10.         0.
03190C                   100.         90.                             46.5
04190C          41.      100.         72.       69.5       17.7       15.5       12.8
05190C         13.6
06190C       -.0025    -.0025       -.005      -.125     -.0035                -.0005
07190C       -.0005    -.0005      -.0005                -.0065                -.0085
08190C       -.0015    -.0055      -.0015     -.0035      -.001     -.0015      -.001
09190C        -.002    -.0015       -.003     -.0025       .004     -.0015      -.002
10190C          1.1      .001        .024      -.001        .62       .082
11190C          .03       10.      -.0005     -.0005     -.0005       .011       .004
12190C         .009      .001         1.1        .38        13.        .27     -.0125
13190C         .004    -.0005         1.2        .63        .45       .018        2.1
14190C          .18      .053         4.4        .71     -.0085        41.        7.7
15190C          2.3      340.         20.        27.        .99        .18       370.
16190C          12.                -.0025       .044
17190C
18190C
19190C
20190C                                                     .004     .00233    .000464
21190C
22190C
23190C                                         .0007       .004      .0025
24190C
25190C                    10.          0.        8.3        25.       396.         6.
26190C        2400.     2924.         24.       .031                    5.       28.2
27190C          3.4                             1.08
28190C          2.2       1.5         1.9        1.2        1.0        3.2        1.2
29190C          1.0
30190C           1.                                          1.                    3.
31190C           2.
01190EPLANT E
02190E                                                       1.        10.         0.
03190E                     2.                                         100.
04190E          7.8      100.        100.       100.       100.       100.       100.
05190E         48.5
06190E       -.0005    -.0005       -.001       .063      -.001                -.0005
07190E       -.0005    -.0005      -.0005                -.0015                -.0015
```

STUDY 19 (continued)

```
08190E     -.0005      -.001     -.0005      -.001     -.0005     -.0005     -.0005
09190E     -.0005     -.0005      -.001       .007       .004       .022       .019
10190E        .29     -.0005       .011     -.0005        .13       .006
11190E       .004       .001     -.0005     -.0005     -.0005       .004     -.0005
12190E       .009     -.0005       .094       .071        .92       .002       .035
13190E     -.0005     -.0005        .76        .10       .038       .001        .86
14190E       .035       .043       .018        .13     -.0005        36.        26.
15190E        1.3       290.        9.2        2.9        .39        2.1        70.
16190E        13.                -.0005       .014
17190E
18190E
19190E
20190E                                                  .0012     .00792   .0000016
21190E
22190E
23190E                                      -.00025      .0008     -.0025
24190E
25190E                   7.5         0.        35.       -2.5        78.        8.5
26190E       310.     13120.        10.       .004                    .1        3.6
27190E        3.4                               2.0
28190E
29190E
30190E         1.                                          1.
31190E
01190FPLANT F
02190F                               0.      0.114         1.        10.         4.
03190F                  100.        85.                              100.
04190F       81.7       100.       100.       100.       100.       100.       100.
05190F       32.3                                          1.        10.         0.
06190F     -.0015      -.002     -.0035       .033     -.0025                -.0005
07190F     -.0005     -.0005     -.0005                -.0045                -.0055
08190F      -.001     -.0035      -.001     -.0025     -.0005      -.001     -.0005
09190F     -.0015      -.001      -.002      -.002       .002       .003       .002
10190F        .16     -.0005       .002      -.001        .19       .004
11190F       .004     -.0005     -.0005     -.0005     -.0005       .005     -.0005
12190F       .011     -.0005        .28       .054        .16       .006     -.0085
13190F      -.005       .001        1.5        .49       .024       .021        2.7
14190F        .13       .015       .022         .1        27.        10.        .83
15190F        56.        38.        48.        4.6        15.       490.        2.9
16190F                -.0015       .004               .036983
17190F                                                 .02753
18190F                                               .0021446
19190F    .001992
20190F                                                   .001         0.   .0000043
21190F                              .94        .03        .19        .33        .14
22190F       1.86       5.17       4.27
23190F                                        .0009      .0003     -.0025
24190F
25190F                   7.4         0.        2.4        96.       276.         5.
26190F      1900.      2006.        10.       .004                    .1        16.
```

STUDY 19 (continued)

```
27190F      1.54                           .56
28190F       1.7       1.5       1.1       9.1       1.3       1.1       1.2
29190F       1.3
30190F        1.                                      1.                  1.
31190F        1.
01190GPLANT G
02190G                            0.     0.087
03190G                100.       59.                          64.7
04190G      62.4      100.      100.      100.      100.      100.      100.
05190G      41.4
06190G    -.0005    -.0005    -.0005       .10    -.0005              -.0005
07190G    -.0005    -.0005    -.0005              -.0005    -.0005    -.0005
08190G    -.0005    -.0005    -.0005    -.0005    -.0005    -.0005    -.0005
09190G    -.0005    -.0005    -.0005    -.0005    -.0005      .004      .004
10190G       .23      .001      .007    -.0005       1.2      .032
11190G      .002      .003    -.0005    -.0005    -.0005      .006    -.0005
12190G      .011    -.0005      .089      .017      .036      .001      .014
13190G    -.0005    -.0005       .84       .11      .038       .13       1.6
14190G       .17      .018       .12       .11    -.0005       16.       20.
15190G       1.1       43.       16.       8.7       2.2       1.4       48.
16190G       3.2              -.0005       .32  .0554699              .01062
17190G              .01062                      .0085218
18190G
19190G  .0002118
20190G                                               .0056   .000132  .0000076
21190G                          3.18       .72       .23       .09       .03
22190G       2.9      1.39      1.55
23190G                                -.00025      .011     .0025
24190G
25190G                 7.5        0.       30.       42.      502.        8.
26190G      155.      276.        5.      .003                 -1.      27.2
27190G      72.5                            4.
28190G       1.0       0.7       1.3       1.2       1.1       1.4       1.2
29190G       1.1
30190G        1.                                      1.                  1.
31190G        1.
01190KPLANT K
02190K                            0.     0.084        1.       10.        1.
03190K                100.       77.                          100.
04190K      100.      100.      100.      100.      100.      100.      100.
05190K      39.5
06190K     -.001     -.001     -.002      .017    -.0005              -.0005
07190K    -.0005    -.0005    -.0005              -.0025               -.003
08190K    -.0005     -.002    -.0005    -.0015    -.0005    -.0005    -.0005
09190K     -.001     -.001     -.001     -.001    -.0005    -.0005     -.001
10190K       .19    -.0005       23.    -.0005      .048      .011
11190K      .003    -.0005    -.0005    -.0005    -.0005      .006    -.0005
12190K      .005    -.0005       .19      .027       2.9    -.0005       .32
13190K       .01      .001       .77       .11      .014      .012       .72
14190K      .008       .09      .015      .018     -.001       24.       26.
```

STUDY 19 (continued)

```
15190K        650.      105.       6.8      120.       .71       13.      120.
16190K         87.               -.001      .005
17190K
18190K
19190K
20190K                                              -.00005    .00044  .0000056
21190K
22190K
23190K                                   -.00025     .0008    -.0025
24190K
25190K                   7.2        0.      710.      -2.5      131.        5.
26190K        875.     1256.       14.      .004                  1.      2.73
27190K         3.1                           2.5
28190K         2.4       1.2       1.5       2.7       1.0       0.9       1.0
29190K         0.9
30190K          1.                                      1.                  1.
31190K          1.
01190LPLANT L             67.1                47.5                15.8
02190L       100.0      34.1        0.     0.174        1.       10.        5.
03190L                   42.       1.7                          23.5
04190L        28.0      100.      100.      100.      100.      100.      100.
05190L         9.4
06190L      -.0005    -.0005     -.001       .14    -.0005              -.0005
07190L      -.0005    -.0005    -.0005              -.0015               -.002
08190L      -.0005    -.0015    -.0005      .001    -.0005    -.0005    -.0005
09190L      -.0005    -.0005    -.0035    -.0005    -.0005      .011      .005
10190L         .37      .007      .005    -.0005        .3      .046
11190L        .003      .001    -.0005    -.0005    -.0005      .015      .005
12190L        .026      .001       .99        .2       .51      .002      .031
13190L      -.0005    -.0005       2.4       .54       .25      .033       4.5
14190L         .27                 .23       .24    -.0005      110.       5.3
15190L         2.1      330.       10.       15.       .44       4.6       78.
16190L         2.5              -.0005       2.1    .02308
17190L                                              .04113
18190L
19190L      .04113                                  .00325
20190L                                                .046    .00135  .0000864
21190L                            1.27       .22       .86       .86       .97
22190L        5.51      11.7      1.81
23190L                                   -.00025      .003     .0025
24190L
25190L                   5.8        0.       30.       13.      234.        4.
26190L        555.      725.       42.       .03                  3.      16.3
27190L          .5                           .88
28190L         1.5       1.3       1.6       1.5       1.1       1.1       1.0
29190L         1.1
30190L          1.        2.        2.        2.        1.                  1.
31190L          2.
01190NPLANT N             34.2                33.6                 1.1
02190N        61.7       6.6        0.      .211        1.       10.        6.
```

STUDY 19 (continued)

```
03190N                         2.          2.3                                       48.8
04190N            1.          75.          75.         47.5         43.5         37.4         26.3
05190N          40.7
06190N         -.002        -.002        -.004          .95         .001                    -.0005
07190N        -.0005       -.0005       -.0005                     -.005       -.0055        -.006
08190N         -.001        -.004       -.0015        -.002       -.0005        -.002       -.0005
09190N        -.0015       -.0015       -.0025        -.002         .002         .005         .008
10190N           1.3         .001          .12       -.0005          .12         .008
11190N          .004         .002       -.0005       -.0005       -.0005         .030         .001
12190N          .054         .017          2.1          .51          .19         .063          .40
13190N          .005         .002         580.          .11          .39          .46          80.
14190N           27.          44.         .033         .089        -.002         570.          58.
15190N           1.1        1400.         110.          54.         110.          42.         150.
16190N           41.                     -.002         .033      .006774
17190N                                                             .00673                    .00146
18190N                                                             .00365
19190N        .00231
20190N                                                              .0646       .00055     .0000003
21190N                                    4.45          .10          .39          .21          .10
22190N          2.05          .89         1.66
23190N                                               -.00025         .002       -.0025
24190N
25190N                        7.          20.           0.          36.         286.           9.
26190N          990.        1352.          13.          1.8                        .1         9.24
27190N          12.8                                   11.2
28190N           1.9          1.5          1.0          1.2          1.7          1.3          1.3
29190N           1.2
30190N            1.           2.           2.           2.           1.                       3.
31190N            3.
01190S PLANT S
02190S                                                                1.          10.           5.
03190S                      100.         100.                                    100.
04190S                      100.         100.         100.         100.         100.         100.
05190S          10.7
06190S         -.001        -.001         .012         .085        -.005                    -.0005
07190S        -.0005       -.0005       -.0005                    -.0025        -.006        -.002
08190S        -.0005       -.0015        -.001       -.0015       -.0005       -.0005        -.001
09190S        -.0005       -.0005       -.0005        -.002       -.0025       -.0025       -.0035
10190S          .097         .002         .017       -.0005          .84         .024
11190S          .008         .001       -.0005       -.0005       -.0005         .021         .002
12190S          .016       -.0005         .027          .81          13.         .001         .064
13190S        -.0005       -.0005          .29          .28         .005       -.0005           1.
14190S            .1         .016         .006          .01        -.001          11.          37.
15190S           2.5          24.          15.          18.          18.          2.8          95.
16190S           1.1                     -.001         .011       .03662
17190S                                                             .00825
18190S                                                             .03868
19190S        .00391
20190S                                                               .015       .00044    .0000033
21190S                                    1.23          .47         1.97         1.11          .66
```

STUDY 19 (continued)

```
22190S      2.68       .65      1.36
23190S                                  -.00025      .074    -.0025
24190S
25190S                 7.8        0.      130.       59.     1035.        7.
26190S      640.      692.      349.        0.                  .3      5.40
27190S      72.5                           72.
28190S       1.7       1.5       1.3       1.4       1.7       2.1       1.3
29190S       1.2
30190S        1.                                      1.                  1.
31190S        1.
01190TPLANT T
02190T                            0.     0.131        1.       10.        0.
03190T                100.       70.                          46.5
04190T      100.      100.      100.       68.      100.      100.      34.5
05190T      43.9
06190T      .002    -.0005    -.0005      .042    -.0005              -.0005
07190T    -.0005    -.0005    -.0005              -.001    -.0005     -.001
08190T    -.0005     -.001    -.0005     -.001     -.001    -.0005    -.0005
09190T    -.0005    -.0005    -.0005    -.0005      .002      .002      .006
10190T      .022      .001      .002    -.0005      .009      .005
11190T      .001      .002    -.0005    -.0005    -.0005      .005    -.0005
12190T      .006      .002       .03       .13       .13      .005    -.0015
13190T    -.0005    -.0005       .29       .04      .045      .002       .57
14190T      .059      .058      .014      .019    -.0005       5.2       36.
15190T       .51       .70       .79       1.9       3.3       1.4       40.
16190T       .95              -.0005      .008    .05196
17190T                                            .02277
18190T                                            .00287
19190T     .0166
20190T                                               .01    .00008   .000004
21190T                          1.85       .26       .67      1.29       .69
22190T      1.74      2.92      1.71
23190T                                  -.00025              -.0025
24190T
25190T                 7.4        0.      300.       32.      414.        5.
26190T      460.      660.       44.        0.                  6.      17.8
27190T      13.6                           6.4
28190T       1.7       1.2       1.0       1.2       1.3       1.1       1.2
29190T       1.0
30190T        1.                                      1.                  3.
31190T        2.
01190U PLANT U
02190U                            0.        0.        1.       10.        0.
03190U                100.      100.                          100.
04190U      12.1      100.      100.      100.      100.      100.      100.
05190U      18.5
06190U    -.0005    -.0005     -.001      .006    -.0005              -.0005
07190U    -.0005    -.0005    -.0005              -.001    -.0005     -.001
08190U    -.0005    -.0005    -.0005    -.0005    -.0005    -.0005    -.0005
09190U    -.0005    -.0005    -.0005    -.0005     -.013    -.0005    -.0405
```

STUDY 19 (continued)

```
10190U          .16         .002         .076       -.0005          .19         .003
11190U         .003       -.0005       -.0005       -.0005       -.0005         .007    -.0005
12190U         .002         .001          .32         .043          .55         .018       .14
13190U       -.0005       -.0005          16.         .099         .058           .1       .12
14190U          .53         .005         .002         .024         .003         180.       37.
15190U         170.          16.          6.4          14.          .24          11.       38.
16190U          2.4                    -.0005         .023       .09303
17190U                                                           .01888                .0015
18190U                                                           .00405
19190U       .00383
20190U                                                               0.       .00008-.00000025
21190U                                   19.7          2.7         3.67         1.47      1.77
22190U          7.3         3.83         7.93
23190U                                            -.00025         .001        .0025
24190U
25190U                       7.3           0.         120.          24.         748.        9.
26190U         770.        1331.         111.         .014                       3.5      14.6
27190U         5.44                                   2.96
28190U          1.7          1.4          1.7          1.7          1.5          0.9       1.2
29190U          1.1
30190U           1.                                                  1.                   1.
31190U           1.
01190VPLANT V
02190V                                     0.           0.           1.          10.        0.
03190V                      100.          94.                                    36.
04190V          9.4
05190V         43.4
06190V       -.0005       -.0005         .003         .089       -.0005                 -.0005
07190V       -.0005       -.0005       -.0005                     -.001       -.0005     -.001
08190V       -.0005       -.0005       -.0005        -.001       -.0005       -.0005    -.0005
09190V       -.0005       -.0005       -.0005        -.001        -.001         .005      .003
10190V          .36       -.0005       -.0015       -.0005          .01         .009
11190V         .011       -.0005       -.0005       -.0005       -.0005         .005    -.0005
12190V         .002         .001          .19         .022          1.1       -.0005      .012
13190V       -.0005       -.0005          3.1           2.          .01         .073       4.7
14190V          .31         .066         .012          .12       -.0005          43.        2.
15190V           1.          45.          4.2          9.5           4.          7.4       24.
16190V          1.4                    -.0005         .041       .01863                 .00538
17190V                    .00538                                 .03109
18190V                                                           .00002
19190V       .00237
20190V                                                            .0057      .000088  .0000264
21190V                                   1.53          .49          .38          .55      1.16
22190V          .39         2.26         1.98
23190V                                            -.00025         .004       -.0025
24190V
25190V                       7.1           0.           .4         -2.5         128.        9.
26190V         360.                                   .003                        .5
27190V          2.5                                    1.7
28190V          1.2          0.7          1.3          1.4          0.8          1.1       1.2
```

STUDY 19 (continued)

```
29190V         1.1
30190V          1.
31190V                                                    1.
01190W PLANT W
02190W                        0.112     0.152        1.       10.        0.
03190W                94.       50.                          55.2
04190W         6.3       42.       41.      37.5      37.5      24.8      19.6
05190W        10.3
06190W      -.0015    -.0015    -.0025       .17     -.001              -.0005
07190W      -.0005    -.0005    -.0005              -.0035              -.0045
08190W      -.0005     -.003     -.001    -.0015    -.0005     -.005    -.0005
09190W       -.001     -.002    -.0015     -.002     -.002     -.005     -.003
10190W      -.0005      .003    -.0065    -.0005    -.0065      .011
11190W        .006      .003    -.0005    -.0005    -.0005    -.0035    -.0005
12190W        .023      .006       .31        2.       .55      .018      .033
13190W       -.002      .002       .06      .072      .024      .048       .67
14190W         .22      .028      .011      .079     9.001       94.      660.
15190W         1.2       16.       .12       30.       7.3       12.       8.3
16190W         11.              -.0015      .054    .06161
17190W                                              .00576
18190W                                              .00016
19190W       .0248
20190W                                                  0.    .00123  .0000145
21190W                        2.09       .34      1.32       .85       .57
22190W         .42      1.41      1.17
23190W                                 .0005   -.00025      .004
24190W
25190W                 8.1        0.      950.       84.      837.        5.
26190W       1250.     1648.      217.      .003                  .1       15.
27190W         .38                          .075
28190W         1.3       1.3       1.7       2.2       1.3       1.3       1.1
29190W         1.3
30190W          1.                                    1.                  3.
31190W          3.
01190XPLANT X
02190X                           0.     0.132        1.       10.        0.
03190X                100.      100.                          100.
04190X        100.      100.      100.      100.      100.      100.      100.
05190X        25.1
06190X      -.0005    -.0005    -.0005       .03    -.0005              -.0005
07190X      -.0005    -.0005    -.0005               -.001    -.0005     -.001
08190X      -.0005     -.001    -.0005    -.0005    -.0005    -.0005    -.0005
09190X      -.0005    -.0005    -.0005    -.0005    -.0005    -.0005      .001
10190X         .13    -.0005      .037    -.0005       1.9      .004
11190X      -.0005    -.0005    -.0005    -.0005    -.0005      .005    -.0005
12190X      -.0005      .007       .14      .023       2.5    -.0005      .022
13190X        .005      .001       .14       .87      .006       .12       2.5
14190X        .028      .027      .026      .018     -.001       23.        9.
15190X        130.       2.9       29.       18.       8.2       4.6       33.
16190X         11.              -.0005      .052
```

STUDY 19 (continued)

```
17190X
18190X
19190X
20190X                                   .0001  .0000033  .000044
21190X
22190X
23190X                           .0009   .0009   -.0025
24190X
25190X            7.2       0.     140.     15.     258.      7.2
26190X   285.    437.      1.3     .039              .01     13.5
27190X    .05                        0.
28190X    1.9     1.5      1.2      1.3     1.6      0.9      1.2
29190X    1.0
30190X     1.                                1.               1.
31190X     1.
01190DPLANT D                                          0.
02190D                      0.       0.               10.      6.
03190D           100.                                100.
04190D   100.
05190D   46.7
06190D
07190D
08190D
09190D
10190D
11190D
12190D
13190D
14190D
15190D
16190D
17190D
18190D
19190D
20190D
21190D
22190D
23190D                          -.00025    .002     .006
24190D
25190D
26190D
27190D
28190D    5.2     2.3      2.6      3.4     2.6      2.6      1.6
29190D    1.2
30190D     1.                                1.
31190D
01190HPLANT H                                         28.
02190H                      0.    0.164               10.      5.
03190H            96.
04190H   100.
```

STUDY 19 (continued)

```
05190H     31.3
06190H
07190H
08190H
09190H
10190H
11190H
12190H
13190H
14190H
15190H
16190H
17190H
18190H
19190H
20190H
21190H
22190H
23190H
24190H                                  -.00025      .006      .0025
25190H
26190H
27190H
28190H      1.5       1.4       1.2       1.4       1.3       0.9       1.1
29190H      1.0
30190H      1.                                      1.
31190H
01190JPLANT J
02190J                                                         48.
03190J                100.      0.        0.                   10.       10.
04190J      100.                                               100.
05190J      39.1
06190J
07190J
08190J
09190J
10190J
11190J
12190J
13190J
14190J
15190J
16190J
17190J
18190J
19190J
20190J
21190J
22190J
23190J
                                 -.00025   -.00025      .0025
```

STUDY 19 (continued)

```
24190J
25190J
26190J
27190J
28190J      1.3       1.4       1.7       1.1        .8       1.3       1.1
29190J      1.0
30190J       1.                                      1.
31190J
01190MPLANT M      52.6                90.8                34.5
02190M     26.3      78.8     0.166     0.124                 10.        1.
03190M               100.                                    100.
04190M      60.
05190M     22.8
06190M
07190M
08190M
09190M
10190M
11190M
12190M
13190M
14190M
15190M
16190M
17190M
18190M
19190M
20190M
21190M
22190M
23190M                             -.00025      .004    -.0025
24190M
25190M
26190M
27190M
28190M      1.4       0.9       1.4       1.9       0.9       1.3       1.1
29190M      1.0
30190M       1.        2.        1.        1.        1.
31190M
01190PPLANT P
02190P                         0.        0.                 10.        1.
03190P                43.                                    100.
04190P     100.
05190P     49.0
06190P
07190P
08190P
09190P
10190P
11190P
```

STUDY 19 (continued)

```
12190P
13190P
14190P
15190P
16190P
17190P
18190P
19190P
20190P
21190P
22190P
23190P                           -.00025  -.00025    .0025
24190P
25190P
26190P
27190P
28190P    1.7      1.3      1.6      1.4      1.0      1.0      1.3
29190P    1.2
30190P     1.                                  1.
31190P
01190RPLANT R     90.2              97.2                0.
02190R   93.2     87.1       0.       0.               10.       5.
03190R             93.                                16.5
04190R    8.0
05190R   26.7
06190R
07190R
08190R
09190R
10190R
11190R
12190R
13190R
14190R
15190R
16190R
17190R
18190R
19190R
20190R
21190R
22190R
23190R                           -.00025  -.00025    .0025
24190R
25190R
26190R
27190R
28190R    1.6      1.4      1.6      1.5      1.5      1.0      1.2
29190R    0.9
30190R     1.       1.       1.       3.       1.
```

STUDY 19 (continued)

```
31190R
01190YPLANT Y
02190Y                        0.135        0.                 10.       10.
03190Y              100.                                     100.
04190Y     100.
05190Y     33.2
06190Y
07190Y
08190Y
09190Y
10190Y
11190Y
12190Y
13190Y
14190Y
15190Y
16190Y
17190Y
18190Y
19190Y
20190Y
21190Y
22190Y
23190Y                                -.00025      .003    -.0025
24190Y
25190Y
26190Y
27190Y
28190Y      2.0       1.8       1.6       1.7       1.5       1.6       1.1
29190Y      1.1
30190Y       1.                                  1.
31190Y
01190ZPLANT Z
02190Z                        0.131     0.114                 10.        1.
03190Z               18.                                     100.
04190Z     42.6
05190Z     18.6
06190Z
07190Z
08190Z
09190Z
10190Z
11190Z
12190Z
13190Z
14190Z
15190Z
16190Z
17190Z
18190Z
```

STUDY 19 (continued)

19190Z							
20190Z							
21190Z							
22190Z							
23190Z				-.00025	.012	.0025	
24190Z							
25190Z							
26190Z							
27190Z							
28190Z	1.2	0.8	1.8	0.8	0.9	1.8	1.2
29190Z	1.1						
30190Z	1.				1.		
31190Z							

APPENDIX B

DRAFT REPORT FROM DON LEWIS

Don Lewis, a biostatistician employed in the Process Measurements Branch, IERL/EPA, examined the data from the three pilot studies. His draft report follows.

Introduction

The Process Measurements Branch, IERL/RTP has developed a phased sampling and analytical strategy for environmental assessment programs, the first phase of which is directed at the quantification of mass emissions for inorganic elements and organic classes (1,2). Included in this phase, Level 1, is a set of biological tests designed to determine the biological effects, both ecological and health-related, of the samples collected.

The purpose of this report is to describe the apparent relationships between the biological test results and the chemical analyses of the samples, as well as provide a descriptive analysis of the data used to quantify these relationships. Discussion of the results and suggestions for future work will follow thereafter.

The data represent biological and chemical analyses from pilot studies of four pollution sources: (1) secondary wastewater from U.S. textile plants (textile study), (2) air emissions from a pressurized fluidized-bed combustion unit (Exxon study), (3) air emissions from a low-BTU gasification facility (Radian study), and (4) gaseous effluents from a collection of different industrial sites (Mitre study).

A total of 51 samples were collected. In most cases only one sample was taken per plant; in the case of the Exxon study all of the samples were collected at the same plant but under varied conditions.

Of the 51 samples 23 were collected from the textile plants, eight of which had little or no chemical analysis performed, rendering them useless for the purposes of this report.

Twelve samples were analyzed from the Exxon and Radian studies and 16 from the Mitre study. Complete data are not available from any of the studies; hence, the statistical analyses represent a "piecemeal" approach, the results of which should pertain only to the corresponding source of data.

The data were compiled by N. H. Gaskins and F. W. Sexton, Systems Measurement Division, Research Triangle Institute, Research Triangle Park, North Carolina from references 3-7 and by personal contact with the contractors who collected the data. References 1-7 should be consulted for specific information about the nature of the data, how it was collected, by whom, etc.

The Data

One hundred and ninety-one variables were measured in the study, 150 of which are chemical analyses. The chemical analyses represent concentrations of the 74 primary elements, the 26 multi-media environmental goal (MEG) values, the eight liquid chromatography (LC) fractions, the seven gas chromatography (GC) values, and measurements of 35 other physical and chemical parameters of interest. A list of these parameters is given in Table 1.

The forty-one biological parameters represent 31 tests for mutagenicity, cytotoxicity, lethality to selected aquatic organisms and rats, and growth inhibition of selected algal species, plus the Salmonella test strain revertent ratios that form the basis of the Ames test for mutagenicity. Reference 8 can be consulted for details regarding the Ames test and related information. The individual tests are listed in Table 2 with a brief description included.

A severe limitation in this study is the amount of data available for analysis. More than 80% of the biological data was not collected, or the tests were not performed. Table 3 gives a breakdown by study of the biological parameters and the data that is available. Note that even when data are available for a certain parameter, there may not be a distribution of the responses, eliminating the possibility of evaluating the relationship of that variable to the chemical factors.

The body of data do not represent a homogenous sample which can be considered in total. The analyses of the textile samples were made on secondary effluent rather than untreated effluent. The non-textile samples represent effluent from dissimilar pollution sources to that of the textile plants; hence, the samples are not particularly comparable, at least chemically. This will be discussed further in the Results section. Henceforth, all results will be reported by study-type.

An additional problem with much of the chemical data is the presence of missing values. Since much data were missing, it was necessary to determine whether the data were in fact not collected or whether the result fell below a "minimum detectable limit (MDL)", and therefore was not reported. All possible missing values which were not reported due to the latter case were identified and replaced by one-half of the MDL. The decision was made to substitute these values in order to minimize any possible bias (negative or positive) in the results. Therefore, all remaining missing values represent data which were not collected or which were not analyzed.

The Mitre study is included in the data set although the only analyses that were completed were the 74 elemental values and the RVI biological parameter. Since the goal of the study was to quantitate the biological/chemical relationship in the data, the Mitre study data was not included in the descriptive section on the chemical analyses in this report.

Methods

The statistical methods utilized are grouped according to the two-fold purpose of this report: descriptive analysis of the parameters and statistical analysis of the relationship between the parameters.

The descriptive portion of the study utilized typical summary statistics: sample mean ($\overline{X}$), sample standard deviation (A), minimum (min), maximum (max), and coefficient of variation (CV).

To quantify relationships between parameters both Pearson's product-moment correlation and Spearman's rank correlation were employed as well as multiple regression techniques (9). Few multivariate methods could be utilized due to the severe restrictions missing data places on these methods. Spearman's rank correlation was preferred to the product-moment correlation because fewer assumptions are required of the data. In particular Pearson's correlation presumes that the two variables follow the bivariate normal distribution, a very tenuous assumption to make about any of these variables. Generally, the chemical data are highly skewed upward while concentrated near the censored value or MDL below.

When either Pearson's correlation or multiple regression is used, natural-log transformations of the data are made to ease this difficulty.

Results

The results are presented in two sections: (a) descriptive analysis and (b) analysis of biological/chemical associations.

(a) Descriptive Analysis. Descriptive statistics of the chemical parameters are listed by study in Tables 4 and 5 (SSMS - elemental analysis) and Tables 6 and 7 (other physical and chemical measurements). The non-textile plants are considered a homogenous sample for these purposes (Mitre study samples not included in these results).

In general the data show high degrees of variability even within the aforementioned categories. Most of the parameters have a lower range of zero or the MDL. The CV's of these parameters generally exceed 1.0 and others exceed 2.0, implying high variability of the sample values relative to their average concentrations. CV's exceeding 2.0 usually indicate a sample mean which is dominated by a maximum value entirely out of range of the remainder of the data. In these cases the sample mean is not a good measure of central tendency and should be disregarded. If it can be determined, the sample median is a better statistic to consider.

Clearly the textile data exhibit substantially lower concentrations and levels of the chemical parameters than do the non-textile data, due to the difference in the nature of the two sources, as mentioned earlier.

The biological tests for which enough data were available for correlation analysis are noted by a * in Table 2. Descriptive statistics for the continuous-type variables and distributions of the discrete variables are given in Tables 8 and 9.

In general the test results do not exhibit a wide range of response to the pollutant samples. There was no distribution of response to the textile effluent in the Ames test with continuous data (AMES) and the Ames test with discrete data (AMES2). In fact AMES and AMES2 in each case registered no mutagenicity. The non-textile data exhibit a somewhat wider response with three of eight samples showing high mutagenicity according to AMES and three of nine samples exhibiting at least slight mutagenicity according to AMES2. The Rabbit Alveolar Macrophage-test with discrete data (RAM2) exhibited similar distribution in the non-textile data. Data were available on the Grass Shrimp (GS) test and the Fresh Water Fish (FWF) test only for the textile plants; however, these data were distributed across the range of responses.

These variables represent the data available for statistical analysis among those variables measured. Other variables where data were available but were entirely or predominately constant in value are RLD50, FWA, FWF96, DAPH48, PRAM, PATP, SWF at 24, 48, and 96 hours and GS at 24, 48 and 96 hours. The remaining biological variables were predominately missing values or were not measured.

Also compiled as a part of the data set but not summarized here are the ten variables representing the revertant ratios, from which AMES is quantitated. Data are available on these variables from the textile, Exxon and Radian studies.

(b) Statistical Analysis. Where data were available, each of the biological variables was correlated with each of the chemical variables by computing the Spearman's rank correlation. The coefficients were then tested under the hypothesis of no association, or equivalently, that the true correlation is equal to zero. The significance level of each correlation coefficient was then calculated, and those whose two-sided p-values fell below 0.05 were judged to exhibit "significant" association. Rather than listing all of the correlations computed (over 2000), only those which were significant according to this criterion are listed and are found in Tables 10, 11 and 12.

In general there is not a great deal of evidence showing strong associations between the chemical tests and biological results. The number of significant correlations cited does not exceed the number that should be expected given a significance level of 0.05 and the assumption that there are no underlying relationships being measured. No particular pattern emerges from the correlations which are significant, i.e., the biological tests do not agree to a large extent in the "choices" of chemicals to which they are sensitive.

To qualify the above remarks, the following points must be made:

(1) The sample sizes involved in the bulk of the correlations are less than 15. With such small sample sizes very large correlations must result before significance is reached. In other words there may be underlying associations that were not identified due to the paucity of data. In addition, much of the data is missing and possible relationships could not be measured.

(2) Many of the chemical concentrations may not be in the range of response of the biological parameter. Because a large number of the chemicals were scattered near the MDL, no range in the biological tests was observed; hence, no correlation resulted.

(3) The biological result represents a response to a host of chemical substances and to possible interactions of those substances. A response can't be linked directly to a specific chemical in the presence of others. One can control for the effects of extraneous variables in the analysis; however, to do so without knowing which to control for (out of a multitude to choose from) is a huge task which these data do not warrant.

With that in mind each biological test will now be discussed in regard to the chemical association observed. The following tests involve the non-textile data only.

AMES was found to be positively correlated with the elements Bi, Pb, La, and MEG categories 2 and 15. (Recall that AMES did not vary in the textile data.) AMES2 was found to correlate positively with the same chemical constituents as AMES with the exception of Lu, denoting general agreement between the two. In addition AMES2 correlated negatively with Cl, CO_3^-, and SO_3^- and positively with F. Note the very small sample sizes involved here.

RAM2 was found to correlate positively with I, MEG categories 1, 21, and 25 and Hg-AA (non-textile data only). RATP was found to correlate negatively with MEG categories 1, 21, and 25. Not surprisingly RAM correlates with the same variables, since RAM is a function of RATP (RAM = (RATP + RVI)/2). The RVI test did not correlate with any of the chemical variables, despite the largest sample size (n=28) available to any of the biological variables.

The following correlations were based upon the textile data only. RT was found to be positively correlated with Pb, Zr, and Fe while negatively correlated with Ta, Yb, MEG category 1 and LC fraction 4. SWA exhibited positive correlations with Sm and LC fraction 2 and negative correlations with La, Zr, V, and NO_3^-. GS exhibited positive associations with Pr, Ag, Y, Se, and Ni and negative correlations with Dy, Eu, Be, and LC fraction 6. The FWF test correlates positively with Ag, Zr, Y, Sr, Rb, Ni, and NO_3^-. Negative correlations are found with Dy, Sm, and Cl.

The Salmonella strain ratios were also correlated with the chemical parameters. TA1535- was found to correlate with 18 variables, and 13 of these correlations were negative. Hence, in general this ratio decreases with increasing chemical concentrations. TA1535+ correlates with eight chemical parameters, six of which are also negative. TA1537- correlated with only three chemicals. TA1537+ was sensitive to 13 chemical parameters, and eight of these correlations were negative. TA98- was positively correlated with four chemical variables and TA98+ with 12, all of which were positive. The most sensitive of the strains to the chemical constitution of the samples was TA100-, correlating positively with 38 parameters, all of which were primary elements. TA100+ related inversely with six of seven chemical parameters. TA1538- correlated only with Hf, Si, and CO_3^-. TA1538+ correlated positively with eight of ten variables, the others negative. Table 12 lists all of the significant correlations by strain. These results indicate that a greater degree of association between the chemical and the revertent ratios is apparent than indicated by the correlations between the chemicals and AMES.

Evidence for an association between a chemical parameter and the biological response to a pollutant is of greater interest if more than one biological test is associated with that chemical. Table 13 lists the twelve chemical constituents which were found to be associated with at least two biological tests. Of the primary elements, Bi, Pb, Cl, Zr, Ag, Dy, and Y are all significantly related to at least two tests. In addition MEG categories 1, 15, 21, and 25 as well as NO_3^- are associated with at least two tests. The significant associations between these MEG categories and the tests are based upon the non-textile data results.

It should be noted that much of the MEG data from the textile plants is missing, or to be more precise, was not found by the chemical analysis. Only MEG categories 1, 8, 15, and 18 exhibit 8 or more data points. In comparison data from all of the 26 categories were present from the non-textile plants. Hence, an explanation for the lack of correlation between the biological tests and the MEG categories in the textile data is the absence of these constituents in the samples. Had these MEG categories been present, more correlations could have been observed. The necessary point to be made is that the lack of observed correlation is not based upon statistical testing but the result of an absence of data.

As a measure of agreement the rank correlations between each pair of the revertent ratios were computed and are given in Table 14. Note that none of the non-activated strains are associated with their respective activated strains. The overall agreement among the strains is not particularly good, there being only seven significant correlations out of a total of 45 intercorrelations.

A question could be raised here: which of these strains "contributes" the most to the variation of the Ames indicator variable? One possible answer might be found by performing a multiple regression of the strain ratios on AMES. This was accomplished after first logging the values of the ratios.

With a sample size of only nine, it was found that the best pair of predictors of AMES were TA98- and TA1538+, explaining 90% of the variation in AMES. TA98- was most highly correlated (unconditionally) with AMES followed by TA1538- and TA100-. However, both of the latter were found to correlate with TA98- (Table 14); hence, their effects are eliminated after consideration of TA98-. These results should be interpreted with caution since they are based on only nine observations.

An additional indicator of agreement between the biological tests would be the rank correlations among the tests. Table 15 gives those correlations by data source. The results do not reveal a great deal of agreement or association; the significant correlations occur between tests which are either functions of or slightly different versions of one another. Worthy of note is the high correlation between GS and FWF and the inverse correlation between FWF and SWA, all ecologically-oriented tests. The RVI-RATP correlation indicates that the two types of tests involving the rabbit alveolar macrophage are in good agreement.

Probably of greatest interest in this analysis are results aimed at the simultaneous consideration of the chemical variables in relation to one or more biological parameters. This can be accomplished statistically through multivariable analyses by determining the combination of variables and their interactions which explain significantly the variations in the biological parameters. A group of eleven elemental variables identified by IERL chemist, Frank Briden, as potentially toxic were used as the independent variables in regression analyses modelling the biological parameters. The group consisted of Be, Cd, Ti, As, Sb, Pb, Hg, Cr, Se, V, and Te.

For each biological variable, where data were available, a step-wise regression was performed, and independent variables which were found to enter the regression at the 0.05 level of significance were identified. If two or more chemical variables were found to enter the regression, then the respective interaction terms were also tested. Due to the nature of the data, the transformation $X = \log (c+1)$, where C = chemical concentration, was made on each chemical.

The difficulties with missing data arise here to complicate this analysis. When considering a group of variables simultaneously, only those cases (samples) which have complete data on these variables can be used in the analysis. As a result the sample sizes are often reduced drastically, to the point that the statistical results may not have meaning. In addition, the sample size may change with the addition of any new variable to the regression, and the results may change accordingly as cases are added or deleted. Nevertheless, regressions were performed on ten of the biological variables and all of the Salmonella strains. A similar logarithmic transformation was made on the ratios to bring the data in line with the usual regression assumptions of normality in distribution of the dependent variable.

For nine of the ten biological tests none of the eleven elements were found to explain a significant amount of variation in the test. Hence, no relationship between these chemicals and the biological response is apparent. Only for SWA was a variable found to be significant in the regression (the element, CR). However, this relationship should be suspect due to two outliers in the data and the failure of the rank correlation to corroborate this finding.

The ten Salmonella strain ratios were analyzed after first controlling for the effects of the data source (study-type) in the analysis by use of an indicator variable. TA1537- was found to be associated significantly with Cd ($\alpha=0.01$). Note, however, that the rank correlation between these two variables does not substantiate this. None of the remaining strains were found to associate with any of the eleven elements after controlling for study-type. Although the indicator variable for study-type was not generally a significant regressor in those analyses, more often than not the variable explained more variation in the log-ratios than any of the elements.

Additional regression analyses were performed using the MEG categories as regressors. The focus of these investigations was the identification of the sets of MEG values which explain significant variation in the biological variables. One series of regressions was performed for each study-type. Quite strong restrictions on data availability, as mentioned earlier, reduced the choice of variables in each case. For the textile study only MEG categories 1, 8, 15, and 18 were considered. For the non-textile study only those MEG categories which exhibited significant rank correlations with at least one biological test were considered. This group consisted of MEG's 1, 2, 15, 21, 23, and 25.

The results of the analyses for the textile plants were not especially revealing. The only significant relationship between the MEG categories and the biological tests was that between RT and MEG1, corresponding to the significant rank correlation found earlier. All other regressions did not exhibit statistically significant relationship. As a reminder, only MEG categories 1, 8, 15, and 18 were investigated.

For the non-textile plants no relationships were found between the MEG categories and AMES, contrary to the correlation results (Table 10). A strong relationship between AMES2 and MEG2 was observed, accounting for 80% of the variability in AMES2. MEG1 was found to explain a significant portion of the variation in both RAM and RATP. Finally, RVI exhibited a strong association with MEG23. The following comments pertain to these results:

(1) Except for the AMES analysis, they agree with the rank correlation analysis results;

(2) In each case only one MEG category from the group that was considered was found to be significant in the regression. After adjusting for this variable in the regression analysis, none of the others were found to explain a significant amount of the remaining variability. The MEG categories are themselves correlated; therefore, adjusting for the effects of a particular MEG variable will likely rule out the residual effects of the others.

(3) Performing linear regressions on essentially categorical variables using skewed variables as independent variables in the regression is at best a tricky proposition, and results should be interpreted with caution.

Discussion

In a general sense these data do not reveal a large degree of association between the chemical variables and the biological tests. Approximately 2000 correlations were computed and 20 regression analyses performed, and the number of statistically significant results observed did not exceed the number that would be expected if the data were truly random in distribution. As summarized by Table 13, however, the constituents listed there seem to be related to the biological response of the sample effluents. These results are not conclusive but provide evidence for possible associations.

An appropriate questions arises: Why are more associations not found in these data? A number of factors can be identified which may have prevented the discovery of additional relationships.

1) The quality of the data. For the purposes of these analyses the quality of the data was very poor. Missing data reduced the sample sizes available for many of the variables and prevented analyses of others. The multivariable analyses such as regression were severely restricted by this problem; hence, the question of interaction or synergy remains unanswered by this report.

Also, the data were generally skewed upward and clustered about zero and the MDL. Since few variables were distributed evenly across the range of values, standard statistical procedures involving the assumption of normality are not useful in this setting. One should also ask: do the data span the range of toxicity? Apparently the body of the chemical data does not fall in the range of response for most of the biological tests, especially the textile data. Few high correlations are observed possibly for this reason alone.

2) Sample size. The sample sizes were generally too small to elicit a significant result even if an association were present. No general rule exists concerning minimum sample size requirements; however, pairwise comparisons involving fewer than 15 observations will not be significant at the 0.05 level unless the absolute value of the rank correlation coefficient is greater than 0.455 (10). The fact that the analyses were performed by study-type rather than over the entire body of data further reduced the sample sizes.

3) The nature of the sample medium. The nature of the sample medium prevented a realistic assessment of the association between any of its particular constituents and a biological test. The test result probably represented a response to the entire medium, all of its constituents, not to an isolated constituent. The effects of one constituent should only be assessed after controlling for the effects of certain others in the analysis. Therefore, there arises a real need to focus on a collection of variables rather than individual variables. This presents the dilemma of multivariable methods, such as regression analysis, which require complete data. Furthermore, when evaluating observational data which do not arise from a designed study or an experiment, the results may not be valid due to confounding of the effects, that is, an artificial relationship between a biological response and a chemical parameter resulting purely from relationships to a third variable. Regardless, such methods were only used in a limited fashion in this analysis.

4) There are no relationships here. At least at the level of the chemical constituents found in these samples, there may be no relationships to be measured. Assuredly, there are associations between some of these tests and the chemical parameters; however, the chemical data were simply not in the range of toxicity of the biological tests to elicit enough gradation of response to measure an association.

Suggestions for future work would include the following:

(a) collection of additional, more complete data;

(b) collection of better quality data; and

(c) laboratory verification of the associations.

If the goal of a future study were to determine the relationships between the chemical makeup of and biological responses to an effluent, then additional, more complete data is needed. Data should be collected at fewer sites with more replications per site. In the setting of the present study, it is difficult to identify any semblance of a random sample. The sampling units are plants, all of which are unique. Each datum or sample unit arose from a unique source, and thus random variation has no meaning unless it can be assumed that all of the data sources are in some sense homogenous.

Even if that assumption can be made, the question arises: Are other sources of variation (which are measurable), such as day-to-day and within-plant variation controlled for? If these sources of variation cannot be controlled for in the sampling, they can be controlled for in the analysis, provided pertinent data are collected.

More complete data should be collected so that missing entries can be eliminated. Efforts should be made to ensure that all of the parameters are measured from each sampling unit. In addition, there are process variables such as temperature or humidity which ought to be collected but were not. Perhaps a protocol which would spell out clear instructions for data collection would be useful for these purposes.

Finally, samples need to be collected where there will be a range in the chemical response and the biological response. This goal may operationally contradict some of the above recommendations, especially if there is little within-plant variability. However, when the collection of samples yields no biological response or no range of response, no knowledge is gained with regard to chemical/biological associations. This leads to a final recommendation.

Even if the above measures are taken, there remains a need for controlled laboratory investigation of these relationships, for two reasons:

(i) Too many uncontrolled factors remain to statistically describe the association between the chemical factors and the biological effects. From these data it is not possible to know the cause of a high biological response. One chemical alone, two or more in combination, or two or more interacting may all be the cause of such a response. But the answer probably won't be ascertained without a carefully controlled experiment in which all extraneous factors can be kept constant.

(ii) In a laboratory setting the chemical composition which is subjected to biological testing can be simulated to induce a range of biological response, such that the main effects of each constituent and the corresponding interactions can be measured and statistically analyzed. Expensive field sampling and chemical analyses can be avoided, as well.

Summary

The purpose of this report is to describe the relationships between the chemical analyses and biological tests associated with samples from four pollution sources. A total of 191 variables were measured, 150 of which were chemical variables. A severe limitation in this endeavor was the amount and quality of the data available for statistical analysis, much of which was missing or essentially contant in value.

In general the results do not reveal a strong degree of association between the chemical analyses and biological tests. A few of the chemical variables were found to correlate highly with more than one biological test. Although not conclusive, these results provide evidence for possible associations to further investigate.

Of primary interest is the identification and measurement of interactions among the chemical constituents. These issues could not be studied in this report. Since multivariable methods are involved in such analyses, the need for higher quality, more complete data is apparent. The control of extraneous factors and identification of probable sources of variation is also an important effort. Ideally the experimental setting would produce the most useful data for these purposes.

References

1. Lentzen, D. E., Wagoner, D. E., Estes, E. D., and Gutknecht, W. F., IERL-RTP Procedures Manual: Level 1 Environmental Assessment, Second Edition, (Draft), September 1978.

2. Dorsey, J. A., Johnson, L. D., Statnick, R. M., and Lochmuller, C. H., Environmental Assessment Sampling and Analysis: Phased Approach and Techniques for Level 1, EPA-600/2-77-115, June 1977.

3. Brusick, D., and Hart, R., Internal Communication, Litton Bionetics, August 1978.

4. Allen, J. M., Howes, J. E., Jr., Miller, S. E., and Duke, K. M., Comprehensive Analysis of Emissions from Exxon Fluidized-Bed Combustion Miniplant Unit (Draft), Battelle Columbus Laboratories, September 1977.

5. Unknown, Environmental Assessment: Source Test and Evaluation Report for a Commercial Chapman Low-BTU Gasification Facility, (Draft), Radian Corporation, Austin, Texas, EPA Contract 68-02-2147.

7. Mahar, H., Evaluation of Selected Methods for Chemical and Biological Testing of Industrial Particulate Emissions, EPA-600/2-76-137, May 1976.

8. Ames, B., McCann, J., and Yamasaki, E., "Methods for Detecting Carcinogens and Mutagens with the Salmonella/Mammalian-Microsome Mutagenicity Test", Mutation Res., Vol. 31, 1975, pp 347-364.

9. Neter, J., and Wasserman, W., Applied Linear Statistical Models, Richard D. Irwin, Inc., 1974.

10. Snedecor, G. W., and Cochran, W. G., Statistical Methods, Sixth Edition, Iowa State Univ. Press. Ames, Iowa, 1967, p 557.

TABLE 1
ADDITIONAL PHYSICAL AND CHEMICAL PARAMETERS

Parameter	Description-Units
1. Cl^-	gms/100 gms of sample
2. F^-	gms/100 gms of sample
3. $SO_4^=$	gms/100 gms of sample
4. NO_3^-	gms/100 gms of sample
5. NO_2^-	gms/100 gms of sample
6. $CO_3^=$	gms/100 gms of sample
7. $S^=$	gms/100 gms of sample
8. Cr^-	gm/M^3
9. $SO_3^=$	gm/M^3
10. CN^-	gm/M^3
11. SCN^-	gm/M^3
12. NO_x	ppm
13. O_2	%
14. CO_2	%
15. SO_2	ppm
16. CO	ppm
17. H_2S-COS	ppm
18. HCN	ppm
19. F_2	ppm
20. Cl_2	ppm
21. H_2S	gm/M^3
22. NH_3	gm/M^3
23. Hg-AA	μgm/gm of sample
24. Sb-AA	μgm/gm of sample
25. As-AA	μgm/gm of sample
26. Ph	1-14 scale
27. Acidity	gm/M^3
28. Alkalinity	gm/M^3
29. BOD	gm/M^3
30. COD	gm/M^3
31. DO	gm/M^3
32. Conductivity	μmhos @ 25°C
33. Dissolved Solids	gm/M^3
34. Suspended Solids	gm/M^3
35. Organics	gm/M^3

TABLE 2
BIOLOGICAL RESPONSE VARIABLES

Test	Variable Name	Description
1. Ames test for mutagenicity*	AMES	categorical index of mutagenicity
2. Rabbit Alveolar Macrophage Viability Index*	RVI	# of cells that survive as % of control
3. Rabbit Alveolar Macrophage ATP production*	RATP	10^{-5} g/cell @ dosage of 1000 μg per ml of culture medium (expressed as % of control)
4. Combination of RVI* and RATP	RAM	RAM = 1/2 (RVI + RATP)
5. Rat Test*	RT	Sum of all atypical behavioral and physiological responses
6. Rat LD_{50}	RLD50	gms/Kg of rat body weight at which 50% lethality is estimated
7. Salt Water Algae*	SWA	EC50 measured @ 96 hours as a % of control
8. Fresh Water Algae	FWA	EC20 measured @ 14 days as a % of control
9. Human Lung Fibroblast	WI38	mean of viability index and ATP production for HLF, as % of control
10. RAM - probit	PRAM	inverse of LD50 from probit analysis
11. ATP - probit	PATP	RAM system - inverse of LD50 based upon probit analysis
12-14. Grass Shrimp @ 24, 48, and 96 hrs.	GS24, GS48, GS96	LC50 as a % of aqueous effluent sample
15-17. Fresh Water Fish @ 24, 48, and 96 hrs.	FWF24, FWF48, FWF96	LC50 as a % of aqueous effluent sample

Test	Variable Name	Description
18,19. Daphnia @ 24 and 48 hrs.	DAPH24, DAPH48*	LC50 as a % of aqueous effluent sample
20-22. Salt Water Fish @ 24, 48, and 96 hrs.	SWF24, SWF48 SWF96	LC50 as a % of aqueous effluent sample

The following are versions of the above tests developed by D. Brusick. All are categorical variables ranging from 1 to 4.[2]

23. Ames test for mutagenicity (Brusick)*	AMES2	based upon max. applicable dose
24. RAM test (Brusick)*	RAM2	corresponds to RAM
25. Rat Test	RODENT	categorized version of RT
26. Grass Shrimp*	GS	categorized GS96
27. Daphnia	DAPH	categorized DAPH48
28. WI38-2	WI38-2	categorized WI38
29. Fresh Water Algae	FWA2	categorized version of FWA
30. Fresh Water Fish*	FWF	categorized FWF96

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1. See Reference 3.
2. 1 = not significantly different from control
   2 = up to 1/10 of max. applicable dose
   3 = 1/10 to 1/100 of max. applicable dose
   4 = less than 1/100 of max applicable dose

Tests which are starred by an asterisk are those which have enough data for correlation analysis.

TABLE 3

AVAILABLE DATA FOR ANALYSIS
BIOLOGICAL VARIABLES

Variable	Radian (n=4)	Exxon (n=8)	Textiles (n=23)	Mitre (n=16)
1. AMES	4	6	14**	0
2. RVI	4	8	4	16
3. RATP	4	8	4	0
4. RAM	4	8	4	0
5. RT	3	0	22	0
6. RLD50	3[1]	8[1]	22[1]	0
7. SWA	1	1	22[2]	0
8. FWA	1	1	13	0
9. WI38	0	0	4	0
10. PRAM	4*	4*	21*	0
11. PATP	3*	4*	21*	0
12. GS24	1	0	14[3]	0
13. GS48	1	0	14[3]	0
14. GS96	1	0	14[3]	0
15. FWF24	1	4	0	0
16. FWF48	1	3	0	0
17. FWF96	1	3	0	0
18. DAPH24	1	4	0	0
19. DAPH48	1	4	22	0
20. SWF24	1	0	14[3]	0
21. SWF48	1	0	14	0
22. SWF96	1	0	14	0
23. AMES2	4	6	23**	0
24. RAM2	4	8	4	0
25. WI38-2	1	0	4	0
26. RODENT	3**	6**	23**	0
27. FWA2	0	4	0	0
28. GS	0	0	13	0
29. FWF	0	4	13	0
30. DAPH	0	4	0	0

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* - data are predominately 0's

** - all data are 1's

[1] - all data are 10's

[2] - 13 are 100's

[3] - more than 50% are 100's

TABLE 4

DESCRIPTIVE STATISTICS: ELEMENTS
(Non-textiles, n=12)

Element	N	$\overline{X}$	S	MIN	MAX	C.V.
U	12	409.3	341.6	0	3000	0.83
Th	12	377.9	888.7	0	3000	2.35
Bi	12	63.0	148.4	0	500	2.35
Pb	12	1861.6	4393.9	0	1500	2.36
Tl	12	209.3	560.8	0	2000	2.68
Hg	12	291.7	721.1	0	2500	2.47
Al	12	291.7	721.1	0	2500	2.47
Pt	12	291.7	721.1	0	2500	2.47
Ir	12	125.1	296.8	0	1000	2.37
Os	12	291.7	721.1	0	1000	2.47
Re	12	125.1	296.8	0	1000	2.37
W	12	542.8	1412.8	0	5000	2.60
Ta	12	4792.1	13957.	0	50000	2.93
Hf	12	250.7	592.7	0	2000	2.36
Lu	12	62.6	148.4	0	500	2.37
Yb	12	176.1	560	0	2000	3.18
Tm	12	62.6	148.4	0	500	2.37
Er	12	250.7	592.7	0	2000	2.36
Ho	12	62.7	148.4	0	500	2.37
Dy	12	250.8	592.7	0	2000	2.36
Tb	12	62.7	148.4	0	500	2.37
Gd	12	250.8	592.7	0	2000	2.36
Eu	12	250.7	592.7	0	2000	2.36
Sm	12	376.9	888.7	0	3000	2.36
Nd	12	177.1	362.2	0	1000	2.04
Pr	12	65.3	146.8	0	500	2.25
Ce	12	158.4	283.2	0.5	1000	1.79
La	12	6687.7	19535	0.4	70000	2.92
Ba	12	50557	139617	3	500000	2.76
Cs	12	2256.2	5699.7	0	20000	2.53
I	12	242.2	570.9	0	2000	2.36

Element	N	$\overline{X}$	S	MIN	MAX	C.V.
Te	11	250.7	592.7	0	2000	2.36
Sb	12	79.6	106.0	0.125	350	1.33
Sn	12	8611.5	28095	0	100000	3.26
In	11	125.1	296.8	0	1000	2.37
Cd	11	126.5	296.8	0	1000	2.35
Ag	12	83.7	184.3	0	500	2.20
Pd	12	125.3	296.8	0	1000	2.37
Rh	11	125.3	296.8	0	1000	2.37
Ru	12	750.1	2097.2	0	7500	2.80
Mo	12	8335.4	20336.4	0	70000	2.44
Nb	12	42.1	87.9	0	300	2.09
Zr	12	554.6	1078.7	0	3000	1.95
Y	12	48.0	84.6	0.15	300	1.76
Sr	12	83786	203199	19	700000	2.43
Rb	12	39260	89118	0.5	300000	2.27
Br	11	7030.7	20511.7	0	70000	2.92
Se	6	0.2	0	0	1	0
As	12	13828	41906	0.1	150000	3.03
Ge	11	252.8	591.9	0	2000	2.34
Ga	12	439.3	935.8	0	3000	2.13
Zn	12	4210.9	14081	0	50000	3.34
Cu	12	6867	15365	2.25	50000	2.24
Ni	12	27586	83780	0	300000	3.04
Co	0	-	-	-	-	-
Fe	12	203183	549305	0	$2x10^6$	2.70
Mn	12	1198.5	2785	0	10000	2.32
Cr	12	6723.2	15338	0	50000	2.28
V	12	2124.9	5593	0	20000	2.63
Ti	12	39134	88077	0	300000	2.25
Sc	12	41660803	141018954	0.15	$5x10^8$	3.38
Ca	12	54214875	141294420	0	$5x10^8$	2.61
K	12	869417	2805617	300	10^7	3.22
Cl	8	203.9	464	4	700000	2.27
S	12	12525767	42293741	250	$1.5x10^8$	3.38
P	12	431669	1404728	0	$5x10^6$	3.25

Element	N	$\overline{X}$	S	MIN	MAX	C.V.
Si	12	125875	192961	0	70000	1.53
Al	11	173396	423003	0	1.5×10^6	2.44
Mg	12	1296423	4208895	50	1.5×10^7	3.25
Na	12	167417	563714	0	2×10^6	3.37
F	8	12756	35254	0.2	100000	2.76
B	12	17449	56442	0.02	200000	3.23
Be	12	84170	282048	0	10^6	3.35
Li	11	19151	60251	0	200000	3.15

TABLE 5

DESCRIPTIVE STATISTICS: ELEMENTS
(Textiles, n=23)

Element	N	$\overline{X}$ (x10^{-3})	S (x10^{-3})	MIN (x10^{-3})	MAX (x10^{-3})	C.V.
U	15	1.17	0.67	0.5	2.5	0.57
Th	15	1.1	0.68	0.5	2.5	0.61
Bi	15	2.8	2.9	0.5	12	1.03
Pb	15	160.	237.4	6	950	1.48
Tl	15	1.37	1.34	0.5	5	0.97
Hg	0	-	-	-	-	-
Al*	15	0.5	0	0.5	0.5	0
Pt*	15	0.5	0	0.5	0.5	0
Ir*	15	0.5	0	0.5	0.5	0
Os*	15	0.5	0	0.5	0.5	0
Re	0	-	-	-	-	-
W	15	2.63	1.80	0.5	6.5	0.68
Ta	7	2.0	2.57	0.5	6.0	1.28
Hf	15	3.13	2.39	0.5	8.5	0.76
Lu	15	0.67	0.31	0.5	1.5	0.46
Yb	15	2.13	1.53	0.5	5.5	0.71
Tm	15	0.8	0.37	0.5	1.5	0.46
Ev	15	1.53	0.97	0.5	3.5	0.63
Ho	15	0.57	0.18	0.5	1.0	0.31
Dy	15	1.0	1.19	0.5	5.0	1.19
Tb	15	0.57	0.18	0.5	1.0	0.31
Gd	15	0.93	0.53	0.5	2.0	0.56
Eu	15	0.87	0.48	0.5	2.0	0.55
Sm	15	1.30	1.00	0.5	3.5	0.76
Nd	15	1.70	1.63	0.5	7.0	0.95
Pv	15	2.97	3.54	0.5	13.0	1.19
Ce	15	4.4	5.57	0.5	22	1.26
La	15	6.87	10.32	1.0	40.5	1.50
Ba	15	341.3	375.2	0.5	1300	1.09
Cs	15	1.63	1.72	0.5	7.0	1.05
I	15	155.5	593.3	1.5	2300	3.81
Te	15	0.57	0.18	0.5	1.0	0.31

Element	N	$\overline{X}$ $(x10^{-3})$	S $(x10^{-3})$	MIN $(x10^{-3})$	MAX $(x10^{-3})$	C.V.
Sb	15	378.5	547.5	6.5	1900	1.44
Sn	15	24.13	29.86	3.0	100	1.23
In	0	-	-	-	-	-
Cd	15	6.03	7.15	0.5	30	1.18
Ag	15	667.8	2582	0.5	10000	3.86
Pd*	15	0.5	-	0.5	0.5	0
Rh	15	0.5	-	0.5	0.5	0
Ru	15	0.5	-	0.5	0.5	0
Mo	15	11.33	11.56	3.5	43	1.02
Nb	15	1.17	1.42	0.5	5.0	1.21
Zr	15	13.97	14.40	0.5	54	1.03
Y	15	2.90	4.40	0.5	17	1.51
Sv	15	452	564	27	2100	1.24
Rb	15	315	517	17	2000	1.64
Br	15	2418	4377	36	13000	1.81
Se	15	26.4	69.3	0.5	270	2.62
As	15	92.1	131.4	1.5	400	1.42
Ber	15	2.67	2.87	0.5	10	1.07
Gia	15	1.1	1.2	0.5	5.0	1.09
Zn	15	41437	149067	60	580000	3.59
Cu	15	0.383	0.512	0.04	2	1.33
Ni	15	0.160	0.274	0.005	1	1.71
Cob	15	0.700	0.117	$5x10^{-4}$	0.46	0.16
Fe	15	7.37	20.17	0.12	80	2.76
Mn	15	1.99	6.92	0.008	27	3.47
Cr	15	3.29	11.72	0.005	44	3.56
V	15	0.494	1.254	0.002	4.4	2.53
Ti	15	0.122	0.173	0.01	0.71	1.41
Sc	15	2.40	7.19	$5x10^{-4}$	27	2.99
Ca	15	90.28	144.4	5.2	570	1.50
K	15	67.51	165.4	0.83	660	2.45
Cl	15	68.81	169.1	0.51	650	2.45
S	15	205.4	354.6	0.70	1400	1.72
P	15	21.77	28.50	0.12	110	1.30
Si	15	23.31	29.82	1.9	120	1.27
Al	15	11.86	27.69	0.24	110	2.33
Mg	15	41.10	124.6	0.18	490	3.03

Element	N	$\overline{X}$ (x10^{-3})	S (x10^{-3})	MIN (x10^{-3})	MAX (x10^{-3})	C.V.
Na	15	96.48	96.28	2.9	370	0.99
F	14	13.67	23.58	0.95	87	1.72
B	1	-	-	-	-	-
Be	15	0.001	0.001	5x10^{-4}	0.004	1.00
Li	14	0.204	0.552	0.005	2.1	2.74

*all values = 1/2 MDL

TABLE 6

DESCRIPTIVE STATISTICS: PHYSICAL AND CHEMICAL PARAMETERS
(Textiles, n=15)

Chemical	N	$\overline{X}$	S	MIN	MAX	C.V.
Cl^-	0					
F^-	0					
$SO_4^=$	15	127.3	200.4	0	646	1.57
NO_3^-	15	0.001	0.002	0	0.008	2.00
NO_2^-	15	∿0	∿0	0	0.0005	-
$CO_3^=$	0					
$S^=$	0					
LC1	11	3.290	5.59	0.005	19.7	1.69
LC2	11	0.724	0.799	0.03	2.7	1.10
LC3	11	0.929	1.071	0.005	3.67	1.15
LC4	11	0.649	0.499	0.005	1.47	0.76
LC5	11	0.556	0.577	0.005	1.77	1.03
LC6	11	2.478	2.137	0.390	7.30	0.86
LC7	11	2.748	3.376	0.005	11.7	1.22
LC8	11	2.458	1.995	1.17	7.93	0.81
GC7	0					
GC8	0					
GC9	0					
GC10	0					
GC11	0					
GC12	0					
GC13	0					
Hg-AA	15	$4x10^{-4}$	$2.5x10^{-4}$	$2.5x10^{-4}$	$9x10^{-4}$	0.62
Sb-AA	14	0.009	0.020			2.22
As-AA	15					

Chemical	N	$\overline{X}$	S	MIN	MAX	C.V.
NO_x	0					
O_2	0					
CO_2	0					
SO_2	0					
CO	0					
H_2S-COS	0					
HCN	0					
F_2	0					
Cl_2	0					
Ph	15	7.473	0.856	5.8	10.0	0.11
ACIDITY	15	1.333	5.164	0	20	3.87
ALKALINITY	15	170.8	283.2	0	950	1.65
BOD	14	42.96	46.27	2.5	168	1.07
COD	15	471.6	433.7	78	1652	0.91
DO	15	6.88	1.70	4	9	0.24
COND	15	910	643.6	155	2400	0.70
DISSOLVED SOLIDS	14	2310.9	3240.8	276	13120	1.52
SUSPENDED SOLIDS	14	77.23	110.02	1.3	349	1.42
CV^-	15	0.141	0.461	0	1.8	3.26
$SO_3^=$	0					
H_2S	15	2.981	5.122	0.01	20	1.71
ORGANICS	14	17.03	15.70	2.73	63.70	0.92
NH_3	15	13.80	24.27	0.05	72.5	1.75
CN^-	0					
SCN^-	0					

Chemical	N	$\overline{X}$	S	MIN	MAX	C.V.
As-AA	6	52.83	19.43	33	85	0.36
NO_x	0					
O_2	0					
CO_2	0					
SO_2	0					
CO	0					
H_2S-COS	0					
HCN	0					
F_2	0					
Cl_2	0					
Ph	0					
ACIDITY	0					
ALKALINITY	0					
BOV	0					
COD	0					
DO	0					
COND	0					
DISSOLVED SOLIDS	0					
SUSPENDED SOLIDS	0					
CV^-	0					
$SO_3^=$	7	428611	731898	20	$1.5x10^6$	1.70
H_2S	0					
ORGANICS	0					
NH_3	0					
CN^-	0					
SCN^-	0					

TABLE 7

DESCRIPTIVE STATISTICS: PHYSICAL AND CHEMICAL PARAMETERS

(Non-textiles, n=12)

Chemical	N	$\bar{X}$	S	MIN	MAX	C.U.
Cl^-	11	10636.5	23791.9	0	64000	2.23
F^-	12	208.3	606.7	0.006	2100	2.91
$SO_4^=$	8	50007	92577	~0	200000	1.85
NO_3^-	8	37.50	69.44	~0	150	1.85
NO_2^-	8	6225	17286	~0	49000	2.77
CO_3^-	7	10.70	23.45	0.1	63.4	2.19
$S^=$	6	0.195	0.429	0.003	1.065	2.20
LC1	5	180.9	331.5	0	767	1.84
LC2	5	125.6	209.2	0	494	1.66
LC3	5	138.5	190.0	0	461	1.41
LC4	5	28.60	38.17	0	93	1.33
LC5	5	13.16	19.22	0	42.5	1.46
LC6	5	64.1	143.3	0	320.5	2.23
LC7	5	108.5	242.6	0	542.5	2.23
LC8	5	112.4	251.3	0	562	2.23
GC7	5	217.7	283.6	0	659	1.30
GC8	5	282.1	447.8	0	1038	1.58
GC9	5	95.9	124.2	0	266	1.29
GC10	5	26.6	35.1	0	65	1.31
GC11	5	43.2	58.0	0	118	1.34
GC12	5	33.5	44.7	0	88	1.33
GC13	5	79.7	135.2	0	313.5	1.69
Hg-AA	9	0.604	1.076	0	2.5	1.78
Sb-AA	6	5.433	3.738	2.0	10	0.68

TABLE 8

DESCRIPTIVE STATISTICS: BIOLOGICAL TESTS
Continuous Variables

Test	Study	N	$\bar{X}$	S	MIN	MAX	C.U.
RVI	non-textiles	12	67.19	33.34	0	102	0.50
RVI	Mitre	16	58.91	24.29	15.8	111.4	0.41
RATP	non-textiles	12	58.51	34.19	0	109.4	0.58
RAM	non-textiles	12	62.87	32.93	0	98.7	0.52
RT	textiles	22	3.45	3.56	0	10	1.03
SWA	textiles	13	71.46	34.87	1.7	100	0.49
DAPH48	textiles	22	57.70	41.23	1	100	0.71

Note: Variables cited here are only those which have sufficient data for correlation analysis.

TABLE 9

DESCRIPTIVE STATISTICS: BIOLOGICAL TESTS
Discrete Variables

Variable	Study-Type	Response 1	Response 2	Response 3	Response 4	Total
AMES	Textiles	14	0	0	0	14
	Non-Textiles	5	0	0	3	8
AMES2	Textiles	23	0	0	0	23
	Non-Textiles	7	2	0	1	9
RAM2	Textiles	1	3	0	0	4
	Non-Textiles	0	2	1	0	12
GS	Textiles	8	0	5	0	13
	Non-Textiles	0	0	0	0	0
FWF	Textiles	7	4	2	0	13
	Non-Textiles	2	1	1	0	4

TABLE 10

STATISTICALLY SIGNIFICANT RANK CORRELATIONS
(Non-textile data)

Test	Chem. Parm.	N	r	p-value[1]
AMES	Bi	10	0.808	<.01
	Pb	10	0.688	.03
	Lu	10	0.631	.05
	MEG2	9	0.769	.02
	MEG15	9	0.691	.04
AMES2	Bi	10	0.819	<.01
	Pb	10	0.644	.04
	Cl	6	-0.828	.04
	F	6	0.840	.04
	MEG2	9	0.791	.01
	MEG15	9	0.707	.03
RAM	I	12	-0.733	<.01
	COD	12	0.627	.03
	MEG1	9	-0.746	.02
	MEG21	9	-0.732	.03
	MEG25	9	-0.758	.02
RAM2	I	12	0.661	.02
	COD	12	-0.751	<.01
	MEG1	9	0.821	<.01
	MEG21	9	0.783	.01
	MEG25	9	0.824	<.01
RATP	I	12	-0.797	<.01
	COD	12	0.641	.03
	MEG1	9	-0.746	.02
	MEG21	9	-0.732	.03
	MEG25	9	-0.758	.02
RVI[2]	I	28	-0.438	.02
	Br	27	-0.429	.03
	Se	28	-0.461	.01
	Ca	28	0.410	.03
	MEG1	9	-0.797	.01
	MEG21	9	-0.800	.01
	MEG23	9	-0.673	.05
	MEG25	9	-0.810	.01
	NO_2^-	8	0.708	.05

[1] two-sided p-value

[2] includes Mitre data

TABLE 11

STATISTICALLY SIGNIFICANT RANK CORRELATIONS
(Textile data)

Test	Chem. Parm.	N	r	p-value[1]
GS	Dy	13	0.568	.04
	Eu	13	0.588	.04
	Pv	13	0.560	.05
	Ag	13	0.654	.02
	Y	13	0.583	.04
	Se	13	0.574	.04
	Ni	13	0.614	.03
	U	13	0.785	<.01
	Pb	13	0.571	.04
	LC6	10	-0.640	.05
FWF	Dy	13	0.613	.03
	Ag	13	0.632	.02
	Y	13	0.613	.03
	Ni	13	0.632	.02
	U	13	0.579	.04
	Pb	13	0.693	<.01
	Sm	13	0.563	.05
	Zr	13	0.667	.01
	Sr	13	0.596	.03
	Rb	13	0.617	.03
	Cl	13	-0.573	.04
	Ce	13	0.554	.05
	NO_3^-	13	0.648	.02
RT	Pb	14	0.555	.04
	Ta	6	0.920	<.01
	Yb	14	0.535	.05
	Ev	14	0.539	.05
	Zr	14	0.582	.03
	Fe	14	0.593	.03
	MEG1	10	-0.812	<.01
	LC4	10	-0.680	.03
	LC5	10	-0.767	.01
SWA	Sm	13	-0.552	.05
	Zr	13	-0.742	<.01
	V	13	-0.554	.05
	Ce	13	-0.687	<.01
	NO_3^-	13	-0.550	.05
	LC2	10	0.632	.05
DAPH48	Ce	14	-0.647	.01
	La	14	-0.596	.03
	Zr	14	-0.557	.04
	Mn	14	-0.553	.04
	Ca	14	-0.771	<.01
	NO_3^-	14	-0.589	.03

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[1] two-sided p-value

TABLE 12

STATISTICALLY SIGNIFICANT RANK CORRELATIONS
STRAIN REVERTANT RATIOS
(Textile and Non-textile data)

Strain	Chem. Parm.	N	r	p-value[1]
TA1535-	Hg	24	0.576	<.01
	Re	24	0.566	<.01
	Ta	24	0.479	.03
	Ce	24	-0.657	<.01
	La	24	-0.565	<.01
	Ba	24	-0.442	.03
	Sb	24	-0.402	.05
	In	24	0.580	<.01
	Zr	24	-0.422	.04
	Y	24	-0.450	.03
	Sr	24	-0.416	.04
	Cu	24	-0.502	.01
	Co	24	-0.437	.03
	Ti	24	-0.489	.02
	K	24	-0.470	.02
	S	24	-0.411	.05
	Li	24	-0.409	.05
	LC8	16	0.662	<.01
TA1535+	F	24	0.407	.05
	Cl^-	9	-0.890	<.01
	Cr^-	14	0.569	.03
	MEG3	12	-0.694	.01
	MEG5	12	-0.741	<.01
	MEG6	10	-0.754	.01
	MEG13	9	-0.773	.02
	MEG14	9	-0.674	.05
TA1537-	Cd	24	0.409	.05
	Pd	21	-0.561	<.01
	F	24	0.519	<.01
TA1537+	U	24	-0.393	.05
	Fe	24	-0.542	<.01
	V	24	-0.437	.03
	Zr	24	-0.420	.04
	Ti	24	-0.434	.03
	P	24	-0.481	.02
	H_2S	14	-0.518	.05
	Sb-AA	17	-0.475	.05
	LC7	16	0.591	.02
	MEG1	20	0.589	<.01
	MEG8	20	0.634	<.01
	MEG18	20	0.680	<.01
	MEG21	9	0.710	.03

Strain	Chem. Parm.	N	r	p-value[1]
TA78-	Ga	24	0.404	.05
	LC1	16	0.600	.01
	LC3	16	0.693	<.01
	MEG15	17	0.670	<.01
TA98+	Bi	24	0.444	.03
	Cd	24	0.499	.01
	Ag	24	0.466	.02
	Nb	24	0.513	.01
	Br	24	0.512	.01
	Se	24	0.431	.04
	NO_3^-	20	0.553	.01
	LC1	16	0.524	.04
	MEG1	20	0.513	.02
	MEG15	17	0.518	.03
	MEG21	9	0.786	.01
	MEG25	9	0.743	.02
TA100-	U	24	0.453	.04
	Th	24	0.457	.03
	Bi	24	0.767	<.01
	Pb	24	0.484	.02
	Tl	24	0.543	<.01
	Ah	24	0.478	.02
	Pt	24	0.479	.02
	Os	24	0.479	.02
	Lu	24	0.518	.01
	Yb	24	0.423	.04
	Tm	24	0.531	<.01
	Er	24	0.461	.02
	Ho	24	0.480	.02
	Dy	24	0.473	.02
	Tb	24	0.535	<.01
	Gd	24	0.433	.04
	Eu	24	0.401	.05
	Nd	24	0.504	.01
	Pv	24	0.553	<.01
	Ce	24	0.403	.05
	La	24	0.448	.03
	Te	24	0.474	.02
	Cd	24	0.469	.02
	Rh	24	0.474	.02
	Ru	24	0.481	.02
	Mo	24	0.542	<.01
	Nb	24	0.501	.01
	Y	24	0.401	.05
	Rb	24	0.400	.05
	Se	24	0.422	.04
	Ge	24	0.434	.03
	Ga	24	0.535	<.01

Strain	Chem. Parm.	N	r	p-value[1]
TA100- (cont.)	Ir	24	0.478	.02
	V	24	0.474	.02
	K	24	0.412	.05
	Al	24	0.479	.02
	Be	24	0.443	.03
	Zn	24	0.452	.03
	Hg-AA	21	0.548	.01
	Sb-AA	17	0.771	<.01
	As-AA	18	0.554	.02
	LC7	16	-0.650	<.01
	MEG2	9	0.728	.03
	MEG15	17	0.590	.01
	Do	14	0.628	.02
TA100+	Ag	24	-0.420	.04
	B	24	-0.424	.04
	Ca	24	-0.403	.05
	Ho	24	-0.443	.03
	Si	24	-0.402	.05
	Sn	24	-0.410	.05
	LC6	16	0.506	.05
	LC7	16	0.527	.04
	BOD	13	0.642	.02
TA1538-	Hf	9	0.751	.02
	Si	9	0.622	.05
	CO_3^-	7	-0.778	.04
TA1538+	Cl^-	9	-0.667	.05

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[1] two-sided p-value

TABLE 13

CHEMICAL PARAMETERS ASSOCIATED WITH MULTIPLE BIOLOGICAL TESTS

Parameter	Biological Tests
Ag	GS, FWF
Bi	AMES, AMES2
Ca	DAPH48, RVI
Ce	SWA, FWF, DAPH48
Cl	AMES2, FWF
Co	RAM, RAM2, RATP
Dy	GS, FWF
I	RAM, RAM2, RATP, RVI
Pb	AMES, AMES2, RT, GS, FWF
Se	GS, RVI
Y	GS, FWF
Zr	DAPH48, RT, SWA
NO_3^-	DAPH48, FWF, SWA
MEG1	RAM, RAM2, RATP, RVI, RT
MEG15	AMES, AMES2
MEG21	RAM, RAM2, RATP
MEG25	RAM, RAM2, RATP, RVI

TABLE 14

RANK CORRELATIONS AMONG STRAINS

(Textile and Non-textile data)

	TA1535+	T1537-	TA1537+	TA98-	TA98+	TA100-	TA100+	TA1538-	TA1538+
TA1535-	0.324	-0.291	0.180	0.093	-0.074	-0.007	0.050	0.293	-0.100
TA1535+		0.110	0.062	0.615**	0.066	0.225	0.375	0.223	0.733*
TA1537-			0.318	-0.044	0.363	-0.180	-0.106	0.056	0.474
TA1537+				0.010	0.307	-0.106	0.214	0.217	0.231
TA98-					0.150	0.431*	0.355	0.630*	0.554
TA98+						0.434*	0.211	0.625*	0.646*
TA100-							0.028	0.421	0.492
TA100+								0.284	0.225
TA1538-									0.523

* two-sided p-value <.05
** two-sided p-value <.01

TABLE 15

RANK CORRELATIONS AMONG BIOLOGICAL TEST

Textile Data

	FWF	RT	SWA	DAPH48
GS	0.866**	-0.051	-0.417	-0.498
FWF		0.052	-0.702**	-0.680*
RT			-0.156	0.209
SWA				0.398

Non-Textile Data

	AMES	RAM	RAM2	RVI	RATP
AMES	0.902**	-0.596	0.412	-0.466	-0.596
AMES2		-0.518	0.458	-0.450	-0.517
RAM			-0.760**	0.909**	0.986**
RAM2				-0.760**	-0.760**
RVI					0.853**

* two-sided p-value <.05
** two-sided p-value <.01

APPENDIX C

"GOOD" CORRELATIONS FOUND IN THIS DATA SET

Matrices are presented showing all correlations among data pairs where the correlation coefficient is greater than 0.50 and the significance factor is less than 0.05 (95 percent level of significance). Such "good" correlations are presented for each study individually, all studies considered together, all liquid samples, and then all solid samples.

TABLE C-1. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 6, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests*	Biological tests, health-related							
	RAM1000	VIABIND	ATP	PROBVI	AMES1	OTHRAT	AMES2	RAM
Ba*					-.95 (4)		-.95 (4)	
Cd*						-.99 (3)		
Br*	-.99 (3)	-.99 (3)	-.99 (3)					
Cu*				-.97 (4)				-.97 (4)
Fe*	.99 (4)	.98 (4)	.99 (4)					
Cr*				-.98 (4)				-.98 (4)
V*	.99 (4)	.99 (4)	.99 (4)					
Ca*					-.96 (4)		-.96 (4)	
S*				.98 (4)				.98 (4)
P*					-.95 (4)		-.95 (4)	
Si*					-.99 (4)		-.99 (4)	
MEG1*	-.97 (4)	-.97 (4)	-.97 (4)					
MEG8*	-.99 (4)	-.99 (4)	-.99 (4)	.96 (4)				.96 (4)
MEG18*	-.99 (4)	-.99 (4)	-.98 (4)	.97 (4)				.97 (4)
MEG21*	-.99 (4)	-.98 (4)	-.99 (4)					
MEG23*	-.99 (4)	-.99 (4)	-.99 (4)					
MEG25*	-.99 (4)	-.99 (4)	-.99 (4)					

*The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-2. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 6, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological test, health-related	Biological test, health-related							
	RAM1000	ATP	PROBVI	PROBATP	AMES1	RATWT	AMES2	RAM
VIABIND	.99 (4)	.99 (4)		-.99 (3)				
ATP	.99 (4)							
PROBATP	-.99 (3)	-.99 (3)						
TA1537M			.98 (4)					.98 (4)
TA1537P					.99 (4)		.99 (4)	
TA98P				.99 (3)	.99 (4)	.99 (3)	.99 (4)	
TA100P					.99 (4)		.99 (4)	
TA1538P					.99 (4)		.99 (4)	
RAM			.99 (4)					

TABLE C-3. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 10, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related					
	RAM 1000	ATP	PROBVI	AMES1	AMES2	RAM
U*				.86 (6)		
Th*				.84 (6)		
Bi*					.85 (6)	
W*					.82 (6)	
Hf*				.87 (6)	.90 (6)	
Lu*					.81 (6)	
Yb*			-.98(4)			
Er*					.81 (6)	
Ho*				.84 (6)	.86 (6)	
Cs*				.85 (6)	.84 (6)	
Ag*				.97 (6)	.99 (6)	
As*				.91 (6)	.96 (6)	
Zn*			-.98 (4)			
Fe*			-.97 (4)			
Cr*					.86 (6)	
K*			-.96 (4)			
S*			-.99 (4)			
Na*			-.95 (4)			
Be*				.92 (6)		.95 (6)
MEG1*						.95 (5)
MEG2*						.99 (5)
MEG16*						.95 (5)
MEG24*		.97 (4)				
MEG25*						.97 (5)
FM			-.99 (4)	.92 (6)	.95 (6)	
CO^{3}E	.83 (6)	.83 (6)				
LC1						.99 (5)
LC2						.98 (5)
LC3						.92 (5)
GC8						.94 (5)
Sb-AA				.96 (4)		
As-AA				.99 (4)		

*The transformation $x = \log (c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-4. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 10, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological tests, health-related						
	RAM1000	VIABIND	ATP	PROBATP	AMES1	AMES2	RAM
VIABIND	.96 (8)						
ATP	.96 (8)	.84 (8)					
PROBATP			.96 (4)				
TA1535P					.83 (6)		
TA98M						.92 (6)	
TA100M							.96 (6)
TA1538M					.97 (6)	.90 (6)	.89 (6)
TA1538P					.88 (6)		.89 (6)
AMES2					.97 (6)		
RAM				.99 (4)			

TABLE C-5. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 10, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related				
	RAM1000	VIABIND	ATP	AMES1	AMES2
Th*				.85 (6)	.83 (6)
Bi*					.83 (6)
Pb*				.85 (6)	.83 (6)
Tl*				.82 (6)	.84 (6)
W*				.82 (6)	.84 (6)
Hf*				.85 (6)	.87 (6)
Lu*				.84 (6)	.85 (6)
Er*				.88 (6)	.89 (6)
Ho*				.84 (6)	.85 (6)
Dy*					.83 (6)
Tb*				.82 (6)	.84 (6)
Gd*				.82 (6)	.84 (6)
Eu*				.82 (6)	.84 (6)
Pr*					.84 (6)
Ba*					.83 (6)
Cs*				.85 (6)	.83 (6)
Ag*				.84 (6)	.85 (6)
Mo*					.83 (6)
Y*					.83 (6)
Rb*				.85 (6)	.83 (6)
As*					.83 (6)
Ge*				.82 (6)	.84 (6)
Ga*					+.83 (6)
Zn*				.82 (6)	.84 (6)
Ni*					.83 (6)
Mn*				.84 (6)	.85 (6)
Cr*					.84 (6)
Sc*					.83 (6)
Cl*				−.85 (6)	−.83 (6)
Si*					.83 (6)
Al*					.83 (6)
Na*				.82 (6)	.84 (6)
F*				.82 (6)	.84 (6)
Be*				.82 (6)	.84 (6)
Li*				.86 (6)	.84 (6)
MEG3*	.90 (5)		.90 (5)		
MEG7*	.90 (5)		.90 (5)		
MEG8*	.95 (5)		.95 (5)		
CIM	.74 (8)			−.85 (6)	−.83 (6)
FM				.82 (6)	.84 (6)
NO2M		.71 (8)			
LC5	.89 (5)		.89 (5)		

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-6. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05

STUDY 10, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological tests, health-related				
	RAM1000	VIABIND	ATP	AMES1	AMES2
VIABIND	.86 (8)				
ATP	.98 (8)	.76 (8)			
TA98M					.84 (6)
TA98P					.84 (6)
TA1538M				.85 (6)	.83 (6)
TA1538P	−.93 (6)		−.93 (6)	.82 (6)	
AMES2				.98 (6)	

TABLE C-7. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS >0.50 AND SIGNIFICANCE LEVELS <0.05

STUDY 15, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical test	Biological test, health-related	Chemical test	Biological test, health-related	Chemical test	Biological test, health-related
	VIABIND		VIABIND		VIABIND
Mo*	−.70 (16)	V*	−.68 (16)	Be*	−.58 (15)

* The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-8. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS >0.50 AND SIGNIFICANCE LEVELS <0.05

STUDY 15, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical test	Biological test, health-related	Chemical test	Biological test, health-related	Chemical test	Biological test health-related	Chemical test	Biological test, health-related
	VIABIND		VIABIND		VIABIND		VIABIND
Mo*	−.78 (16)	Mn*	.53 (16)	V*	−.65 (16)	Be*	−.69 (15)

*The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-9. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 19, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related				
	PROBVI	PROBATP	OTHRAT	RATWT	CHO
U*		.57 (13)			
Th*	.57 (13)				
Pb*		.60 (13)	.58 (14)		
Tl*	.63 (13)				
W*	58 (13)				
Ta*			.99 (6)		
Hf*	.61 (13)	.56 (13)			
Yb*	.60 (13)	.63 (13)			
Tm*	56 (13)	.59 (13)			
Dy*	.62 (13)				
Tb*	.82 (13)				
Eu*	.68 (13)				
Sm*		.65 (13)			
Nd*	.59 (13)				
Cs*				.61 (15)	
Cd*	.81 (13)				
Ag*	.82 (13)				
Mo*			.79 (14)		
Nb*				.56 (15)	
Zr*		.72 (13)	.62 (14)		
Sr*		.64 (13)			
Rb*	.62 (13)			.55 (15)	
Br*	.67 (13)				
Ga*			.62 (14)		
Ni*			.61 (14)		
Fe*			.54 (14)		
V*	.60 (13)	.65 (13)			
Ti*	.75 (13)				
Li*	–.62 (12)				
MEG1			–.74 (10)		
NO_3M	.85 (13)				
NO_2M	.80 (13)				
LC4			–.70 (10)		
LC5			–.69 (10)		
Sb-AA					–.96 (4)
Ph	.85 (13)				
BOD			.69 (13)		
DO				.52 (15)	
Conductivity	.63 (13)				
Dissolved solids	.66 (12)				

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-10. CHEMICAL AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS $\geq$0.50 AND SIGNIFICANCE LEVELS $<$0.05 STUDY 19, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, ecology-related											
	FWALGAL	SWALGAL	FWFISH96	DAPH48	SWFISH24	SWFISH48	SWFISH96	GSHP24	GSHP48	GSHP96	GRSSHP	FWFISH
U*							-.68 (14)	-.68 (14)	-.65 (14)	-.79 (14)	.78 (13)	
Th*						-.55 (14)		-.73 (14)	-.70 (14)	-.57 (14)		
Pb*	-.58 (15)	-.66 (13)					-.63 (14)	-.58 (14)	-.59 (14)	-.54 (14)		.68 (13)
W*						-.57 (14)		-.76 (14)	-.74 (14)	-.59 (14)		
Hf*						-.59 (14)		-.78 (14)	-.75 (14)	-.61 (14)		
Lu*								-.73 (14)	-.69 (14)	-.60 (14)		
Yb*						-.60 (14)	-.55 (14)	-.79 (14)	-.77 (14)	-.64 (14)	.57 (13)	
Tm*						-.59 (14)	-.58 (14)	-.77 (14)	-.74 (14)	-.62 (14)	.56 (13)	
Er*								-.73 (14)	-.72 (14)	-.61 (14)		
Ho*										-.54 (14)		
Dy*					-.88 (14)	-.87 (14)	-.75 (14)	-.61 (14)	-.63 (14)	-.57 (14)		.72 (13)
Gd*								-.69 (14)	-.67 (14)	-.54 (14)		
Eu*					-.76 (14)	-.87 (14)	-.77 (14)	-.81 (14)	-.81 (14)	-.69 (14)	.63 (13)	.68 (13)
Sm*		-.64 (13)										
Nd*	-.55 (15)											
Ce*	-.65 (15)	-.78 (13)										
Ba*								-.64 (14)	-.60 (14)			
Cs*		-.59 (13)										
Sn*			-.59 (15)					-.59 (14)	-.59 (14)			
Cd*								-.63 (14)	-.58 (14)			
Ag*								-.58 (14)				
Zr*		-.84 (13)			-.58 (14)		-.63 (13)	-.55 (14)	-.57 (14)			.75 (13)
Y*							-.61 (14)					.63 (13)
Sr*		-.68 (13)	-.53 (15)					-.66 (14)	-.64 (14)			.66 (13)
Rb*					-.79 (14)	-.77 (14)	-.66 (14)	-.54 (14)	-.56 (14)			.63 (13)

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-10 (continued)

Chemical tests	Biological tests, ecology-related											
	FWALGAL	SWALGAL	FWFISH96	DAPH48	SWFISH24	SWFISH48	SWFISH96	GSHP24	GSHP48	GSHP96	GRSSHP	FWFISH
Ga*					–.61 (14)	–.59 (14)	–.56 (14)	–.58 (14)	–.63 (14)	–.55 (14)		
Ni*			–.65 (15)					–.71 (14)	–.72 (14)	–.63 (14)	.59 (13)	
Fe*	–.53 (15)	–.61 (13)										
Mr*	–.55 (15)	–.59 (13)										
Cr*	–.61 (14)	–.80 (12)										.59 (12)
V*								–.72 (14)	–.69 (14)	–.59 (14)		
Ti*								–.56 (14)				
Ca*		–.57 (13)		–.79 (14)				–.55 (14)	–.56 (14)			.59 (13)
K*					–.62 (14)							
Cl*			–.52 (15)									
S*	–.71 (15)											
Li*		–.62 (12)										
MEG1*	–.65 (11)											
SO_4E	–.68 (15)	–.69 (13)										
NO_3M	–.53 (15)											
NO_2M								–.55 (14)				
As-AA					–.85 (14)	–.77 (14)	–.60 (14)					
Ph								–.56 (14)				
Acidity	–.55 (15)	–.60 (13)										
Alkalinity					–.59 (14)							
Conductivity								–.66 (14)	–.64 (14)			
Dissolved solids	–.54 (14)											
Cr^{++}		–.60 (13)										.56 (13)
Organics	–.55 (15)		–.68 (14)						–.54 (14)			

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-11. HEALTH- AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS $\geq$0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 19, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, health-related				
	W138-600	VIABIND	ATP	PROBVI	PROBATP
FWALGAL	.97 (4)		.99 (4)		
SWALGAL					−.67 (12)
FWFSH96		−.98 (4)			
SWFSH48				−.67 (12)	
SWFSH96					−.62 (12)
GRSHMP24				−.72 (12)	−.59 (12)
GRSHMP48				−.69 (12)	−.59 (12)
GRSHMP96				−.60 (12)	−.62 (12)
GRSSHP					.62 (12)
FWFSH					.75 (12)

TABLE C-12. ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 STUDY 19, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, ecology-related								
	SWALG	FWFSH96	DAPH48	SWFSH24	SWFSH48	SWFSH96	GRSHMP24	GRSHMP48	GRSHMP96
FWALGAL	.63 (13)								
FWFSH96	.64 (13)								
DAPH48		.60 (21)							
SWFSH48			.56 (13)	.91 (14)					
SWFSH96		.63 (14)		.84 (14)	.89 (14)				
GRSHMP24		.60 (14)		.66 (14)	.89 (14)	.83 (14)			
GRSHMP48		.61 (14)	.56 (13)	.71 (14)	.91 (14)	.85 (14)	.99 (14)		
GRSHMP96		.70 (14)		.64 (14)	.82 (14)	.94 (14)	.89 (14)		
GRSSHP		-.69 (13)		-.62 (13)	-.77 (13)	-.94 (13)	-.83 (13)	-.84 (13)	-.99 (13)
FWFSH	-.71 (12)	-.73 (13)	-.66 (12)	-.77 (13)	-.80 (13)	-.92 (13)	-.74 (13)	-.76 (13)	-.83 (13)

TABLE C-13. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 19, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological tests, health-related				
	WI38-600	CHOMPS	ATP	PROBVI	PROBATP
WI38-600			.99 (4)		
TA98M		-.78 (7)			
TA98P				.56 (21)	
TA100P	-.96 (4)		-.97 (4)		
WI38	-.98 (4)		-.95 (4)		

TABLE C-14. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 19, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related			Chemical tests	Biological tests, health-related		
	PROBVI	PROBATP	OTHRAT		PROBVI	PROBATP	OTHRAT
Pb*		.67 (13)	.55 (14)	Nb*		.72 (13)	
W*		.60 (13)		Zr*		.71 (13)	.58 (14)
Ta*			.92 (6)	Sr*		.62 (13)	
Hf*		.60 (13)		Rb*	.56 (13)	.72 (13)	
Yb*		.69 (13)	.54 (14)	Ni*		.60 (13)	
Tm*		.58 (13)		Fe*			.59 (14)
Er*			.54 (14)	V*		.65 (13)	
Dy*	.68 (13)			MEG1*			-.81 (10)
Tb*	.74 (13)			NO_3M	.58 (13)	.56 (13)	
Eu*	.63 (13)			LC4			-.68 (10)
Sm*		.72 (13)		LC5			-.77 (10)
Nd*	.58 (13)			Ph	.63 (13)		
Cd*	.55 (13)			Cr^{++}	.58 (13)		
Ag*	.63 (13)						

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-15. CHEMICAL AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 STUDY 19, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, ecology-related											
	FWALGAL	SWALGAL	FWFISH96	DAPH48	SWFISH24	SWFISH48	SWFISH96	GSHP24	GSHP48	GSHP96	GRSSHP	FWFISH
U*						-.58 (14)	-.71 (14)	-.63 (14)	-.63 (14)	-.76 (14)	.78 (13)	.58 (13)
Th*						-.63 (14)		-.68 (14)	-.68 (14)	-.57 (14)		
Bi*									-.54 (14)			
Pb*	-.66 (15)		-.59 (15)		-.67 (14)	-.67 (14)	-.61 (14)	-.63 (14)	-.64 (14)	-.57 (14)	.57 (13)	.69 (13)
W*						-.64 (14)		-.68 (14)	-.69 (14)	-.56 (14)		
Hf*						-.64 (14)		-.68 (14)	-.69 (14)	-.56 (14)		
Lu*						-.58 (14)		-.65 (14)	-.70 (14)	-.59 (14)		
Yb*						-.66 (14)		-.70 (14)	-.71 (14)	-.61 (14)		
Tm*						-.68 (14)	-.55 (14)	-.72 (14)	-.72 (14)	-.62 (14)		
Er*						-.63 (14)		-.66 (14)	-.68 (14)	-.59 (14)		
Dy*					-.57 (14)	-.69 (14)	-.64 (14)	-.72 (14)	-.66 (14)	-.65 (14)	.57 (13)	.61 (13)
Gd*						-.61 (14)		-.66 (14)	-.68 (14)	-.56 (14)		
Eu*					-.65 (14)	-.78 (14)	-.65 (14)	-.79 (14)	-.76 (14)	-.69 (14)	.59 (13)	
Sm*	-.52 (15)											.56 (13)
Nd*								-.55 (14)	-.55 (14)			
Ce*	-.53 (15)	-.69 (13)		-.65 (14)								.55 (13)
La*				-.60 (14)								
Sn*			-.53 (15)									
Cd*						-.54 (14)		-.58 (14)	-.57 (14)			
Ag*						-.56 (14)	-.62 (14)	-.61 (14)	-.57 (14)	-.68 (14)	.65 (13)	.63 (13)
Zr*		-.74 (13)		-.56 (14)	-.65 (14)	-.55 (14)						.67 (13)
Y*					-.64 (14)	-.55 (14)	-.67 (14)			-.55 (14)	.58 (13)	.61 (13)
Sr*						-.61 (14)		-.64 (14)	-.65 (14)			.60 (13)
Rb*						-.59 (14)	-.58 (14)	-.59 (14)	-.55 (14)	-.57 (14)		.62 (13)
As*			.52 (15)									

*The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-15 (continued)

Chemical tests	Biological tests, ecology-related											
	FWALGAL	SWALGAL	FWFISH96	DAPH48	SWFISH24	SWFISH48	SWFISH96	GSHP24	GSHP48	GSHP96	GRSSHP	FWFISH
Ga*					−.78 (14)	−.61 (14)	−.56 (14)					
Ni*			−.59 (15)					−.55 (14)	−.59 (14)	−.58 (14)	.61 (13)	.63 (13)
Mr*				−.55 (14)								
Cr*	−.55 (14)											
V*		−.55 (13)	−.53 (15)									
Sc*						−.60 (14)		−.60 (14)	−.59 (14)			
Ca*				−.77 (14)	−.56 (14)	−.55 (14)			−.54 (14)			
Cl*												−.57 (13)
S*	−.61 (15)											
Si*						−.57 (14)		−.57 (14)	−.56 (14)			
Be*						−.58 (14)		−.61 (14)	−.61 (14)			
Li*			−.54 (14)									
MEG1*	.64 (11)											
MEG8*						.65 (10)		.65 (10)	.68 (10)			
NO_3M				−.59 (14)								.65 (13)
NO_2M			−.52 (15)									
LC6						.63 (10)	.65 (10)	.63 (10)		.70 (10)		−.64 (10)
As-AA					−.62 (14)	−.56 (14)						
Conductivity						−.63 (14)		−.66 (14)	−.66 (14)	−.56 (14)		
Organics			−.76 (14)									

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-16. HEALTH- AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 STUDY 19, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, health-related		Biological tests, ecology-related	Biological tests, health-related	
	PROBVI	PROBATP		PROBVI	PROBATP
SWFSH48	-.68 (12)	-.59 (12)	GRSHMP24	-.77 (12)	-.62 (12)
SWFSH96		-.60 (12)	GRSHMP48	-.70 (12)	-.63 (12)
GRSHMP96	-.73 (12)	-.62 (12)	GRSSHP		.61 (12)
FWFSH		.81 (12)			

TABLE C-17. ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 STUDY 19, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, ecology-related									
	SWALGAL	FWFSH96	DAPH48	SWFSH24	SWFSH48	SWFSH96	GRSHMP24	GRSHMP48	GRSHMP96	GRSSHP
FWFSH96	.60 (13)									
DAPH48		.56 (21)								
SWFSH24			.69 (13)							
SWFSH48		.60 (14)	.62 (13)	.84 (14)						
SWFSH96		.67 (14)		.84 (14)	.87 (14)					
GRSHMP24		.60 (14)	.56 (13)	.74 (14)	.98 (14)	.83 (14)				
GRSHMP48		.63 (14)		.73 (14)	.97 (14)	.82 (14)	.99 (14)			
GRSSHP		-.71 (13)		.69 (13)	-.83 (13)	-.96 (13)	-.83 (13)	-.83 (13)	-.96 (13)	
FWFSH	-.70 (12)	-.80 (13)	.68 (12)	.74 (13)	-.77 (13)	-.90 (13)	-.75 (13)	-.73 (13)	-.83 (13)	.87 (13)

TABLE C-18. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 STUDY 19, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological tests, health-related		
	CHOMPS	PROBVI	PROBATP
TA1535M	-.93 (7)		
TA98M	-.90 (7)		
TA98P		.61 (21)	

TABLE C-19. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 ALL STUDIES, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related										
	RAM1000	VIABIND	ATP	PROBVI	AMES1	OTHRAT	RATWT	AMES2	RAM(2)	WI-38(2)	CHO
Th*					.52 (24)						
Bi*					.81 (24)			.98 (25)			
Pb*					.67 (24)	.71 (17)		.56 (25)			
Tl*					.58 (24)						
Hf*					.62 (24)						
Lu*					.57 (24)						
Yb*					.61 (24)						
Tm*					.56 (24)						
Er*					.60 (24)						
Ho*					.63 (24)						
Dy*					.57 (24)						
Tb*					.56 (24)						
Gd*					.56 (24)						
Eu*					.59 (24)						
Sm*					.52 (24)						
Nd*					.53 (24)						
Pr*					.58 (24)						
Ce*										.99 (3)	
Cs*					.61 (24)					.99 (3)	
I*										.99 (3)	
Sb*										.99 (3)	
Sn*										.99 (3)	
Cd*					.51 (24)						
Pd*					.55 (24)						
Nb*					.52 (24)						
Zr*										.99 (3)	
Y*					.51 (24)					.99 (3)	

(continued)

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-19 (continued)

Chemical tests	Biological tests, health-related										
	RAM100	VIABIND	ATP	PROBVI	AMES1	OTHRAT	RATWT	AMES2	RAM(2)	WI-38(2)	CHO
Br*										.99 (3)	
As*										.99 (3)	
Ge*					.50 (24)						
Ga*					.62 (24)						
Cu*					.52 (17)						
Ni*					.95 (17)				-.55 (14)		
Fe*	.62 (14)		.57 (14)						-.77 (14)		
Cr*					.53 (23)	.55 (16)					
Y*						.52 (17)			.55 (14)		
Ti*										.99 (3)	
Si*									-.54 (14)		
Al*									-.60 (13)		
Mg*									-.54 (14)		
MEG1*	-.82 (11)	-.91 (11)	.63 (11)	.76 (16)				.71 (20)	.64 (11)	.99 (3)	
MEG2*								.91 (9)			
MEG3*							.87 (6)				
MEG5*							.87 (6)				
MEG6*				.81 (7)					.80 (9)		
MEG8*	-.82 (11)	-.91 (11)	.62 (11)	.83 (16)				.51 (20)	.71 (11)	.99 (3)	
MEG10*								.90 (11)			
MEG13*				.82 (6)					.80 (9)		
MEG15*					.62 (17)			.91 (17)			
MEG18*	-.82 (11)	-.91 (11)	.62 (11)	.84 (16)					.72 (11)	.99 (3)	
MEG21*	-.88 (9)	-.94 (9)	.79 (9)						.78 (9)		
MEG23*	-.88 (9)	-.95 (9)	.79 (9)	.81 (6)					.85 (9)		
MEG24*					.81 (8)			.94 (8)			
MEG25*	-.88 (9)	-.95 (9)	.79 (9)						.79 (9)		
LC1	-.75 (9)	-.86 (9)		.73 (14)	.84 (17)	.90 (11)		.93 (18)			
LC2	-.78 (9)	-.87 (9)		.61 (14)	.64 (17)	.93 (11)		.92 (18)			
LC3	-.77 (9)	-.87 (9)		.59 (14)	.61 (17)			.90 (18)			

*The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

(continued)

TABLE C-19 (continued)

Chemical tests	Biological tests, health-related										
	RAM1000	VIABIND	ATP	PROBVI	AMES1	OTHRAT	RATWT	AMES2	RAM(2)	WI-38(2)	CHO
LC4	–.77 (9)	–.86 (9)		.59 (14)	.61 (17)	.64 (11)		.90 (18)			
LC5	–.77 (9)	–.86 (9)		.59 (14)	.61 (17)			.90 (18)			
LC6	–.77 (9)	–.86 (9)		.59 (14)	.61 (17)	.93 (11)		.90 (18)			
LC7	–.77 (9)	–.86 (9)		.59 (14)	.61 (17)	.74 (11)		.90 (18)			
LC8	–.77 (9)	–.87 (9)		.60 (14)	.62 (17)	.91 (11)		.91 (18)			
GC8									.94 (5)		
Hg-AA					.55 (21)						
Sb-AA					.90 (21)			.88 (26)			–.96 (4)
As-AA					.90 (18)			.90 (27)			
Ph				.85 (13)							
BOD						.69 (13)					
DO							.52 (15)				
Conductivity				.63 (13)							
Dissolved solids				.66 (12)							
NH_3				.68 (14)							

*The transformation x = log(c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-20. CHEMICAL AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS $\geq$0.50 AND SIGNIFICANCE LEVELS <0.05 ALL STUDIES, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, ecology-related										
	FWALGAL	SWALGAL	FWFSH 24	FWFSH 48	FWFSH 96	DAPH 24	SWFSH 24	SWFSH 48	SWFSH 96	GRSHMP 24	GRSHMP 48
Ba*	-.52 (18)	-.54 (14)									
I	-.50 (18)										
Sb*	-.50 (18)										
Sr*	-.50 (18)	-.63 (14)									
As*	-.54 (18)										
Mn*	-.64 (18)	-.66 (14)									
Cr*	-.51 (17)	-.58 (13)									
Sc*			.99 (3)								
Ca*	-.56 (18)	-.68 (14)									
K*	-.54 (18)										
S*	-.65 (18)	-.62 (14)									
P*	-.62 (18)		.99 (3)			.99 (3)					
Mg*	-.51 (18)										
Be*			.99 (23)	.99 (3)							
Li*		-.72 (13)			-.63 (15)						
MEG1*							-.82 (11)	-.81 (11)	-.71 (11)	-.66 (11)	
MEG3*					.96 (4)						
MEG5*					.96 (4)						
MEG8*							-.82 (11)	-.81 (11)	.71 (11)	-.66 (11)	
MEG18*							-.82 (11)	-.81 (11)	-.72 (11)	-.66 (11)	
$SO_4^=$		-.69 (13)									
Ph										-.56 (14)	
Acidity	-.55 (15)	-.60 (13)									
Alkalinity							-.59 (14)				
Conductivity										-.66 (14)	-.64 (14)
Dissolved solids	-.54 (14)										
Cr^{++}	-.55 (15)	-.60 (13)									
Organics					-.68 (14)						-.54 (14)
NH_3*							-.60 (15)	-.57 (15)	-.56 (15)		

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-21. HEALTH- AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 ALL STUDIES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests,	Biological tests, health-related							
ecology-related	RAM 1000	WI-38600	VIABIND	ATP	PROBVI	PROBATP	TA 1537M	WI-38
FWALGAL		.97 (4)		.80 (7)				–.91 (5)
SWALGAL						–.67 (12)		
SWFSH 24	.94 (5)		.97 (5)		–.79 (15)		–.68 (14)	
SWFSH 48	.94 (5)		.97 (5)		–.86 (15)		–.72 (14)	
SWFSH 96	.98 (5)		.96 (5)		–.75 (15)	–.59 (14)	–.54 (14)	
GRSHMP 24	.97 (5)		.98 (5)		–.78 (15)	–.59 (14)	–.54 (14)	
GRSHMP 48	.97 (5)		.97 (5)		–.73 (15)	–.59 (14)		
GRSHMP 96	.96 (5)		.94 (5)		–.64 (15)	–.61 (14)		
GRSSHP			–.99 (4)			.60 (14)		

TABLE C-22. ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 ALL STUDIES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, ecology-related										
	SWALGAL	FWFSH 24	FWFSH 96	DAPH 48	SWFSH 24	SWFSH 48	SWFSH 96	GSHMP 24	GSHMP 48	GSHMP 96	FWFSH
FWALGAL	.73 (14)										
SWALGAL	--						.62 (13)				
FWFSH 24		--									
FWFSH 48		.99 (3)									
FWFSH 96	.73 (14)			.65 (23)		.69 (16)	.76 (16)				
DAPH 24				.99 (3)							
DAPH 48				--		.57 (16)	.54 (16)				
SWFSH 24	.60 (13)		.63 (16)	.55 (16)	--		.92 (17)				
SWFSH 48			.69 (16)	.57 (16)	.97 (17)	--	.94 (17)				
SWFSH 96	.62 (13)		.76 (16)	.54 (16)	.92 (17)	.94 (17)					
GSHMP 24			.70 (16)	.56 (16)	.77 (17)	.89 (17)	.87 (17)		.99 (17)	.91 (17)	
GSHMP 48			.70 (16)	.58 (16)	.77 (17)	.87 (17)	.87 (17)			.92 (17)	
GSHMP 96			.75 (16)		.70 (17)	.80 (17)	.90 (17)				
GRSSHP			-.65 (14)		-.61 (15)	-.75 (15)	-.91 (15)	-.84 (15)	-.84 (15)	-.99 (15)	-.75 (15)
FWFSH	-.71 (12)		-.75 (14)	-.69 (14)	-.74 (15)	-.77 (15)	-.87 (15)	-.67 (15)	-.69 (15)	-.76 (15)	

TABLE C-23. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS $\geq$0.50 AND SIGNIFICANCE LEVELS $<$0.05 ALL STUDIES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological tests, health-related									
	RAM 1000	WI-38-600	CHOMPS	VIABIND	ATP	PROBVI	PROBATP	AMES1	OTHRAT	AMES2
VIABIND	.90 (16)									
ATP	.91 (16)	.99 (4)		.65 (16)						
PROBVI	-.77 (12)			-.86 (12)						
PROBATP	-.77 (11)				-.89 (11)					
TA1535M						.57 (27)				
TA1535P									.52 (24)	
TA1537P								.52 (23)		.79 (32)
TA98M			-.78 (7)					.63 (23)		
TA98P	-.54 (14)			-.54 (14)				.63 (23)		.91 (32)
TA100M								.70 (23)		
TA100P		-.96 (4)						.58 (23)		.87 (32)
TA1538M								.70 (10)		
TA1538P										.92 (10)
AMES2								.89 (24)		
RAM	-.82 (16)			-.74 (16)	-.75 (16)	.70 (12)	.72 (11)			
WI-38		-.98 (4)			-.93 (5)					

TABLE C-24. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 ALL STUDIES, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related									
	RAM 1000	VIABIND	ATP	PROBVI	PROBATP	AMES1	OTHRAT	RATWT	AMES2	RAM
Bi*						.57 (24)			.57 (25)	
Pb*						.55 (24)	.52 (17)		.53 (25)	
Ce*										–.59 (14)
Cd*				.59 (21)						
Sr*								-.51 (19)		
Rb*								-.63 (19)		
Br*				-.62 (20)						
Ga*						.52 (24)			.52 (25)	–.54 (14)
Fe*							.52 (17)			-.69 (14)
Y*										-.61 (14)
Ti*										-.59 (14)
Sc*								-.54 (19)		
Ca*										-.65 (14)
S*				.51 (21)						
Si*										-.53 (14)
Mg*										-.64 (14)
Be*										–.55 (14)
MEG1*	-.62 (11)		-.68 (11)	.64 (16)			.63 (13)			.72 (11)
MEG2*						.80 (9)			.79 (9)	
MEG3*								.88 (6)		
MEG5*								.88 (6)		
MEG15*						.58 (17)			.58 (17)	
MEG18*			.60 (11)							
MEG21*										.78 (9)
MEG23*		-.67 (9)		.94 (6)	.89 (5)					
MEG25*	–.76 (9)	–.81 (9)	-.76 (9)	.94 (6)						.82 (9)
NO_3				.54 (17)						
NO_2	.73 (10)		.77 (10)	.59 (17)						-.73 (10)
LC1									.57 (18)	
LC2				.58 (14)		.64 (17)			.62 (18)	
LC3						.64 (17)		-.58 (12)	.62 (18)	
LC8										.72 (9)
Hg-AA						.56 (21)			.54 (30)	-.51 (13)
As-AA						.69 (18)			.62 (27)	
Ph				.63 (13)						
DO								.57 (15)		

*The transformation x = log(c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-25. CHEMICAL AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 ALL STUDIES, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, ecology-related										
	FWALGAL	SWALGAL	FWFSH 96	DAPH 48	SWFSH 48	SWFSH 96	GSHMP 24	GSHMP 48	GSHMP 96	GRSSHP	FWFSH
U*										.56 (15)	
Pb*											.53 (15)
W*							–.59 (17)	–.60 (17)			
Ce*	–.69 (18)	–.75 (14)									
La*	–.57 (18)										
Ba*	–.63 (18)										
Cd*							–.52 (17)	–.52 (17)			
Ag*							–.54 (17)	–.53 (17)	–.56 (17)		
Zr*		–.79 (14)									
Sr*	–.58 (18)						–.57 (17)	–.57 (17)			
Rb*	–.63 (18)						–.55 (17)	–.53 (17)	–.50 (17)		
As*	–.60 (18)										
Mn*	–.58 (18)										
Ti*	–.55 (18)										
Sc*							–.52 (17)	–.51 (17)			
Ca*	–.63 (18)			–.58 (17)			–.50 (17)	–.51 (17)			
K*	–.56 (18)										
S*	–.73 (18)										
Si*							–.54 (17)	–.53 (17)			
Mg*	–.52 (18)										
F*	–.51 (16)										
Li*			.63 (15)								
MEG15*			.73 (9)		.81 (8)	.76 (8)	.81 (8)	.79 (8)	.83 (8)		
$SO_4^=$	–.51 (17)	–.55 (17)									
LC6					.63 (10)	.65 (10)	.63 (10)		.70 (10)	–.64 (10)	
Conductivity					–.63 (14)		–.66 (14)	–.66 (14)	–.56 (14)		
Organics			.76 (14)								

*The transformation x = log(c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-26. HEALTH AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 ALL STUDIES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, health-related					
	RAM 1000	VIABIND	ATP	PROBVI	PROBATP	WI-38
SWFSH 24	.89 (5)	.89 (5)	.89 (5)			
SWFSH 48	.89 (5)	.89 (5)	.89 (5)	−.67 (15)	−.62 (14)	
SWFSH 96	.89 (5)	.89 (5)	.89 (5)	−.53 (15)	−.64 (14)	
GRSHMP 24	.89 (5)	.97 (5)		−.82 (15)	−.62 (14)	
GRSHMP 48	.89 (5)	.97 (5)		−.78 (15)	−.63 (14)	
GRSHMP 96	.89 (5)	.97 (5)		−.76 (15)	−.65 (14)	
FWALG			.86 (7)			.95 (5)
GRSSHP				.53 (14)	.65 (14)	
FWFSH					.77 (14)	

TABLE C-27. ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 ALL STUDIES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, ecology-related									
	SWALGAL	FWFSH 96	DAPH 48	SWFSH 24	SWFSH 48	SWFSH 96	GSHMP 24	GSHMP 48	GSHMP 96	GRSSHP
FWALGAL	.55 (14)									
FWFSH 96	.68 (14)	– –	.63 (23)	.61 (16)	.70 (16)	.76 (16)	.62 (16)	.64 (16)	.73 (16)	
SWFSH 24	.60 (13)		.73 (16)		.89 (17)	.87 (17)	.78 (17)	.77 (17)	.74 (17)	
SWFSH 48			.78 (16)			.91 (17)	.93 (17)	.93 (17)	.89 (17)	
SWFSH 96	.56 (13)		.58 (16)				.82 (17)	.82 (17)	.92 (17)	
GSHMP 24			.58 (16)					.99 (17)	.94 (17)	
GSHMP 48			.57 (16)							
GSHMP 96								.93 (17)		
GRSSHP		.66 (14)		.66 (15)	−.79 (15)	.92 (15)	−.84 (15)	.84 (15)	.98 (15)	
FWFSH	.70 (12)	.82 (14)	.67 (14)	.69 (15)	−.72 (15)	.83 (15)	−.61 (15)	.59 (15)	.71 (15)	.73 (15)

TABLE C-28. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 ALL STUDIES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological test, health-related	Biological test, health-related								
	RAM 1000	CHO	VIABIND	ATP	PROBVI	PROBATP	AMES	OTHRAT	AMES2
VIABIND	.83 (16)								
ATP	.89 (16)		.58 (16)						
PROBVI	−.71 (12)		−.87 (12)				.53 (18)		
PROBATP	−.89 (11)			−.95 (11)					
TA1535M		−.93 (7)							
TA1535P								.50 (24)	
TA98M		−.90 (17)							
TA98P	−.66 (14)		−.64 (14)	−.58 (14)	.56 (27)		.51 (23)		
TA100M							.56 (23)		
TA1538P	−.71 (10)		−.66 (10)	−.68 (10)			.79 (10)		.79 (10)
AMES2							.99 (24)		
RAM(2)	−.80 (16)		−.75 (16)	−.70 (16)	.59 (12)	.79 (11)			
WI-38				−.95 (5)					

TABLE C-29. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 ALL LIQUID SAMPLES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related							
	RAM1000	VIABIND	ATP	PROBVI	OTHRAT	RAM	WI-38	CHO
U*			.90 (5)					
Th*			.90 (5)					
Bi*			.90 (5)					
Pb*			.90 (5)		.60 (15)	-.89 (5)		
Tl*			.90 (5)					
Hg*	.99 (3)		.99 (5)					
Au*			.90 (5)			-.99 (3)	-.99 (3)	
Pt*			.90 (5)			-.99 (3)	-.99 (3)	
Ir*			.90 (5)			-.99 (3)	-.99 (3)	
Os*			.90 (5)			-.99 (3)	-.99 (3)	
W*						-.99 (3)	-.99 (3)	
Ta*			.99 (4)		.98 (7)			
Hf*			.90 (5)					
Lu*			.90 (5)					
Yb*			.89 (5)					
Tm*			.90 (5)					
Er*			.90 (5)		.52 (15)			
Ho*			.90 (5)				-.99 (3)	
Dy*			.90 (5)					
Tb*							-.99 (3)	
Gd*			.90 (5)					
Eu*			.90 (5)					
Sm*			.90 (5)					
Nd*			.90 (5)					
Pr*			.90 (5)					
Ce*							-.99 (3)	
La*							-.99 (3)	
Cs*							-.99 (3)	
I*							-.99 (3)	
Te*			.90 (5)				-.99 (3)	
Sb*							.99 (3)	
Sn*							.99 (3)	
In*			.99 (3)					
Cd*							.99 (3)	
Ag*							.99 (3)	
Pd*			.90 (5)			-.89 (5)	-.99 (3)	
Rh*			.90 (5)				-.99 (3)	
Ru*			.90 (5)				-.99 (3)	
Mo*			.90 (5)		.80 (15)			
Nb*							-.99 (3)	
Zr*							.99 (3)	
Y*							.99 (3)	

*The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-29 (continued)

Chemical tests	Biological tests, health-related							
	RAM1000	VIABIND	ATP	PROBVI	OTHRAT	RAM	WI-38	CHO
Br*							.99 (3)	
As*							.99 (3)	
Ge*			.90 (5)					
Ga*			.90 (5)		.64 (15)			
Ni*			.90 (5)		.63 (15)			
Fe*			.88 (5)		.57 (15)	–.93 (5)		
Cr*	.97 (4)		.96 (4)			–.99 (4)		
Ti*							.99 (3)	
Sc*							.99 (3)	
Cl*						.96 (4)		
Na*						–.89 (5)		
MEG1*				.95 (11)		.99 (3)	.99 (3)	
MEG8*				.95 (11)		.99 (3)	.99 (3)	
MEG10*				–.99 (3)				
MEG18*				.95 (11)		.99 (3)	.99 (3)	
Cl^-	.99 (3)	.99 (3)	.99 (3)					
$SO_4^=$						–.99 (4)		
LC4					–.70 (10)			
LC5					–.70 (10)			
SbAA								–.96 (4)
pH				.84 (13)				
BOD					.69 (13)			
Conductivity				.63 (13)				
Dissolved solids				.66 (12)				
NH_3*				.67 (14)				

TABLE C-30. CHEMICAL AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 ALL LIQUID SAMPLES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, ecology-related											
	FWALGAL	SWALGAL	FWFSH24	FWFSH48	FWFSH96	DAPH24	SWFSH24	SWFSH48	SWFSH96	GSHMP24	GSHMP48	FWFSH
Ba*	-.52 (18)	-.54 (14)										
I*	-.50 (18)											
Sb*	-.50 (18)											
Sr*	-.50 (18)	-.63 (14)										
As*	-.53 (18)											
Ni*			.99 (3)			.99 (3)						
Mn*	-.64 (18)	-.66 (14)										
Cr*	-.51 (17)	-.58 (13)										
Sc*			.99 (3)									
Ca*	-.56 (18)	-.68 (14)										
K*	-.54 (18)											
S*	-.64 (18)	-.62 (14)										
P*	-61 (18)		.99 (3)									
Mg*	-51 (18)											
F*	-.52 (16)											
Be*				.99 (3)								
Li*		.72 (13)			-.63 (15)							
MEG1*							-82 (11)	-.81 (11)	-.71 (11)	-.66 (11)		
MEG3*					.96 (4)							
MEG5*					.96 (4)							
MEG8*							-.82 (11)	-.81 (11)	-.71 (11)	-.66 (11)		
MEG18*							-.82 (11)	-.81 (11)	-.72 (11)	-.66 (11)		
SO4E		-.69 (13)										
pH							-.56 (14)					
Acidty	-.54 (15)	-.59 (15)										
Alknty							-.59 (14)					
Condty										-.66 (14)	-.64 (14)	
Dissol	-.54 (14)											
CrM	-.55 (15)	-.60 (13)										.56 (13)
Orgncs					-.68 (14)						-.54 (14)	
NH_3*							-.60 (15)	-.57 (15)	-.56 (15)			

*The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-31. HEALTH- AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05 ALL LIQUID SAMPLES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biology tests, ecology-related	Biological tests, health-related						
	RAM1000	WI-38600	VIABIND	ATP	PROBVI	PROBATP	WI-38
FWALGAL		.97 (4)		.80 (7)			-.91 (5)
SWALGAL						-.67 (12)	
SWFSH24	.94 (5)		.97 (5)		-.79 (15)		
SWFSH48	.94 (5)		.94 (5)		-.86 (15)		
SWFSH96	.97 (5)		.96 (5)		.75 (15)	-.59 (14)	
GRSHMP24	.97 (5)		.98 (5)		-.78 (15)	-.59 (14)	
GRSHMP48	.97 (5)		.97 (5)		-.73 (15)	-.59 (14)	
GRSHMP96	.96 (5)		.94 (5)		-.64 (15)	-.61 (14)	
GRSSHP			-.99 (4)			.60 (14)	
FWFSH						.72 (14)	

TABLE C-32. ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS <0.05 ALL LIQUID SAMPLES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, ecology-related										
	SWALGAL	FWFSH24	FWFSH96	DAPH48	SWFSH24	SWFSH48	SWFSH96	GSHMP24	GSHMP48	GSHMP96	GRSSHP
FWALGAL	.73 (14)										
SWALGAL			.73 (14)		.60 (13)						
FWFSH48		.99 (3)									
FWFSH96					.63 (16)	.69 (16)	.76 (16)	.70 (16)	.70 (16)	.75 (16)	
DAPH24				.99 (3)	.55 (16)						
DAPH48			.65 (23)			.57 (16)	.54 (16)	.56 (16)	.58 (16)		
SWFSH24						.97 (17)	.92 (17)	.77 (17)	.77 (17)	.70 (17)	
SWFSH48							.94 (17)	.89 (17)	.88 (17)	.80 (17)	
SWFSH96								.87 (17)	.87 (17)	.90 (17)	
GRSHMP48								.99 (17)			
GRSHMP96								.91 (17)	.92 (17)		
GRSSHP			-.65 (14)		-.61 (15)	-.75 (15)	-.91 (15)	-.84 (15)	-.84 (15)	-.99 (15)	
FWFSH	-.70 (12)		-.75 (14)	-.69 (14)	-.74 (15)	-.77 (15)	-.87 (15)	-.67 (15)	-.69 (15)	-.76 (15)	-.75 (15)

TABLE C-33. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS <0.05 ALL LIQUID SAMPLES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological tests, health-related			
	RAM1000	WI38600	VIABIND	ATP
VIABIND	.86 (7)			
ATP	.83 (7)	.99 (4)		
PROBVI	-.78 (7)		-.91 (7)	
PROBATP			-.86 (6)	
RAM	-.91 (7)		-.79 (7)	
WI-38		-.98 (4)		-.93 (5)

TABLE C-34. CHEMICAL AND HEALTH- RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05 ALL LIQUID SAMPLES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related						
	RAM1000	ATP	PROBVI	PROBATP	OTHRAT	RATWT	RAM
U*	.90 (5)	.90 (5)					-.95 (5)
Th*	.90 (5)	.90 (5)					-.95 (5)
Bi*	.90 (5)	.90 (5)					-.95 (5)
Pb*	.90 (5)	.90 (5)			.58 (15)		-.95 (5)
Tl*	.90 (5)	.90 (5)					-.95 (5)
Au*	.97 (5)	.97 (5)					-.97 (5)
Pt*	.97 (5)	.97 (5)					-.97 (5)
Ir*	.97 (5)	.97 (5)					-.97 (5)
Os*	.97 (5)	.97 (5)					-.97 (5)
W*			.52 (16)				
Ta*					.84 (7)		
Hf*	.90 (5)	.90 (5)			.56 (15)		-.95 (5)
Lu*	.90 (5)	.90 (5)					-.95 (5)
Yb*	.90 (5)	.90 (5)			.57 (15)		-.95 (5)
Tm*	.90 (5)	.90 (5)					-.95 (5)
Er*	.90 (5)	.90 (5)			.57 (15)		-.95 (5)
Ho*	.97 (5)	.97 (5)					-.97 (5)
Dy*	.90 (5)	.90 (5)					-.95 (5)
Tb*	.97 (5)	.97 (5)					-.97 (5)
Gd*	.90 (5)	.90 (5)					-.95 (5)
Eu*	.90 (5)	.90 (5)					-.95 (5)
Sm*							-.95 (5)
Nd*							-.97 (5)
Pr*	.90 (5)	.90 (5)					-.97 (5)
Cs*						-.64 (16)	
Te*	.97 (5)	.97 (5)					-.97 (5)
Cd*			.57 (16)				
Ag*			.62 (16)				
Pd*	.97 (5)	.97 (5)					-.97 (5)
Rh*	.97 (5)	.97 (5)					-.97 (5)
Ru*	.97 (5)	.97 (5)					-.97 (5)
Mo*	.90 (5)	.90 (5)			.54 (15)		-.95 (5)
Rb*			.60 (16)	.54 (15)		-.54 (16)	
Br*			.51 (16)				
Ge*	.90 (5)	.90 (5)					-.95 (5)
Ga*	.90 (5)						-.95 (5)
Ni*	.90 (5)	.90 (5)					-.95 (5)
Fe*	.90 (5)	.90 (5)			.62 (15)		-.95 (4)
V*	.90 (5)	.90 (5)					-.95 (5)
Sc*			.53 (16)				
Si*			.51 (16)				
Na*	.90 (5)	.90 (5)			.56 (15)		-.95 (5)
Be*							-.95 (5)
MEG1*			.61 (11)		-.82 (11)		
MEG18*					-.63 (11)		
NO_3^-			.55 (15)				
LC5					-.77 (10)		
HgAA							-.83 (7)
pH			.63 (13)				
DO						.57 (15)	
Cr^{++}			.58 (13)				

*The transformation x = log (c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-35. CHEMICAL AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS $\geq$0.50 AND SIGNIFICANCE LEVELS <0.05 ALL LIQUID SAMPLES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, ecology-related										
	FWALGAL	FWFSH96	DAPH48	SWFSH24	SWFSH48	SWFSH96	GSHMP24	GSHMP48	GSHMP96	GRSSHP	FWFSH
U*										.56 (15)	
Pb*											.53 (15)
W*	-.57 (18)						-.59 (17)	-.60 (17)			
Ce*	-.68 (18)										
La*	-.57 (18)										
Ba*	-.62 (18)										
Cd*							-.52 (17)	-.52 (17)			
Ag*							-.54 (17)	-.53 (17)	-.56 (17)		
Zr*	-.64 (18)										
Y*	-.55 (18)										
Sr*	-.58 (18)						-.57 (17)	-.58 (17)			
Rb*	-.63 (18)						-.55 (17)	-.53 (17)	-.50 (17)		
As*	-.60 (18)										
Mn*	-.58 (18)										
Ti*	-.55 (18)										
Sc*							-.52 (17)				
Ca*	-.63 (18)										
K*	-.56 (18)										
S*	-.73 (18)										
Si*							-.54 (17)	-.53 (17)			
Mg*	-.52 (18)										
F*	-.51 (16)										
Li*		-.63 (15)									
MEG15*		.73 (9)		-.78 (8)	-.81 (8)	-.76 (8)	.81 (8)	.79 (8)	.83 (8)		
$SO_4^{=}$	-.51 (17)										
NO_3^{-}	-.55 (17)										
LC6					.63 (10)	.65 (10)	.63 (10)		.70 (10)	-.64 (10)	
Conductivity					-.63 (14)		-.66 (14)	-.66 (14)	-.56 (14)		
Organics		-.76 (14)									

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-36. HEALTH- AND ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS
SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05
ALL LIQUID SAMPLES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biology tests, ecology-related	Biological tests, health-related					
	RAM1000	VIABIND	ATP	PROBVI	PROBATP	WI-38
FWALGAL			.86 (7)			-.94 (5)
SWFSH24	.89 (5)	.89 (5)	.89 (5)			
SWFSH48	.89 (5)	.89 (5)	.89 (5)	-.66 (15)	-.62 (14)	
SWFSH96	.89 (5)	.89 (5)	.89 (5)	-.53 (15)	-.64 (14)	
GRSHMP24		.97 (5)		-.82 (15)	-.62 (14)	
GRSHMP48		.97 (5)		-.78 (15)	-.63 (14)	
GRSHMP96		.97 (5)		.76 (15)	-.64 (14)	
GRSSHP				.53 (14)	.65 (14)	
FWFSH					.77 (14)	

TABLE C-37. ECOLOGY-RELATED BIOLOGICAL TEST COMBINATIONS
SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05
ALL LIQUID SAMPLES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, ecology-related	Biological tests, ecology-related									
	SWALGAL	FWFSH96	DAPH48	SWFSH24	SWFSH48	SWFSH96	GSHMP24	GSHMP48	GSHMP96	GRSSHP
FWALGAL	.55 (14)									
SWALGAL		.68 (14)		.60 (13)		.56 (13)				
FWFSH96			.63 (23)	.61 (16)	.70 (16)	.76 (16)	.62 (16)	.64 (16)	.73 (16)	
DAPH48				.73 (16)	.68 (16)	.58 (16)	.58 (16)	.57 (16)		
SWFSH24					.89 (17)	.87 (17)	.78 (17)	.77 (17)	.74 (17)	
SWFSH48						.91 (17)	.93 (17)	.93 (17)	.89 (17)	
SWFSH96							.82 (17)	.82 (17)	.92 (17)	
GRSHMP24								.99 (17)	.94 (17)	
GRSHMP48									.93 (17)	
GRSSHP		-.65 (14)		-.66 (15)	-.79 (15)	-.92 (15)	-.84 (15)	-.84 (15)	-.98 (15)	
FWFSH	-.70 (12)	-.82 (14)	-.67 (14)	-.69 (15)	-.72 (14)	-.83 (15)	-.61 (15)	-59 (15)	-.71 (15)	.73 (15)

TABLE C-38. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS <0.05 ALL LIQUID SAMPLES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological tests, health-related				
	RAM1000	ATP	PROBVI	PROBATP	CHO
VIABIND			-.81 (7)		
ATP	.79 (7)			-.94 (6)	
PROBATP	-.83 (6)				
TA1535M					-.93 (7)
TA1537M			.51 (22)		
TA98M					-.90 (7)
TA98P	-.97 (5)		.63 (22)		
RAM	-.93 (7)				
WI-38		.95 (5)			

TABLE C-39. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS <0.05

ALL SOLID SAMPLES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related							
	RAM 1000	VIABIND	ATP	PROBVI	PROBATP	AMES1	AMES2	RAM
Bi*	-.87 (9)	-.89 (9)	-.80 (9)			.75 (9)	.97 (9)	.71 (9)
I*	-.86 (9)	-.91 (9)				.69 (9)	.94 (9)	.78 (9)
Br*				.99 (4)	.97 (4)			
Fe*	-.70 (9)							
Ca*	.69 (9)	.79 (9)					-.79 (9)	
Si*							-.69 (9)	
MEG1*	-.84 (8)	-.93 (8)	-.72 (8)				.91 (8)	
MEG2*	-.82 (8)	-.92 (8)	-.71 (8)				.91 (8)	
MEG8*	-.81 (8)	-.91 (8)					.89 (8)	
MEG10*	-.81 (8)	-.91 (8)					.90 (8)	
MEG15*	-.82 (8)	-.92 (8)					.91 (8)	
MEG18*	-.81 (8)	-.91 (8)					.90 (8)	
MEG21*	-.82 (8)	-.91 (8)					.91 (8)	
MEG23*	-.81 (8)	-.91 (8)					.90 (8)	
MEG24*	-.87 (7)	-.94 (7)	-.77 (7)			.80 (7)	.94 (7)	.99 (7)
MEG25*	-.82 (8)	-.92 (8)					.91 (8)	
$CO_3^{=}$	.83 (6)		.83 (6)					
LC1	-.87 (7)	-.91 (7)	-.81 (7)			.79 (7)	.91 (7)	.93 (7)
LC2	-.87 (7)	-.93 (7)	-.77 (7)				.92 (7)	
LC3	-.86 (7)	-.93 (7)	-.76 (7)				.91 (7)	
LC4	-.86 (7)	-.93 (7)	-.76 (7)				.91 (7)	
LC5	-.86 (7)	-.92 (7)	-.76 (7)				.91 (7)	
LC6	-.86 (7)	-.92 (7)	-.76 (7)				.91 (7)	
LC7	-.86 (7)	-.92 (7)	-.76 (7)				.90 (7)	
LC8	-.86 (7)	-.93 (7)	-.76 (7)				.91 (7)	
GC8								.94 (5)
Sb-AA						.96 (4)		
As-AA						.99 (4)		

*The transformation $x = \log(c) + 1$, where c = chemical concentration, was made for each chemical test.

TABLE C-40. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05

ALL SOLID SAMPLES COMBINED, PEARSON CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological test, health-related							
	RAM 1000	VIABIND	ATP	PROBVI	PROBATP	AMES1	AMES2	RAM
RAM 1000		.97 (9)	.98 (9)	-.89 (5)		-.76 (9)		
VIABIND			.90 (9)			-.73 (9)		
ATP				-.96 (5)	-.95 (5)	-.77 (9)		
PROBVI					.99 (5)			
TA1537P	-.77 (9)	-.84 (9)					.90 (9)	
TA98P	-.81 (9)	-.88 (9)	-.70 (9)				.92 (9)	
TA100M			-.70 (9)			.78 (9)		.80 (9)
TA100P	-.78 (9)	-.87 (9)					.89 (9)	.68 (9)
TA1538M						.69 (9)		
TA1538P	-.82 (9)	-.89 (9)	-.71 (9)				.92 (9)	.70 (9)
AMES2	-.87 (9)	-.90 (9)	-.81 (9)			.86 (9)		.81 (9)
RAM	-.78 (9)	-.78 (9)	-.75 (9)			.88 (9)	.81 (9)	

TABLE C-41. CHEMICAL AND HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥ 0.50 AND SIGNIFICANCE LEVELS < 0.05

ALL SOLID SAMPLES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Chemical tests	Biological tests, health-related							
	RAM 1000	VIABIND	ATP	PROBVI	PROBATP	AMES1	AMES2	RAM
Bi*	-.77 (9)		-.83 (9)			.81 (9)	.84 (9)	
Pb*						.68 (9)		
I*	-.83 (9)		-.88 (9)			.77 (9)	.76 (9)	.73 (9)
Cl*						-.85 (6)	-.83 (6)	
P*				-.95 (5)	-.95 (5)			
F*						.82 (6)	.84 (6)	
MEG1*		-.73 (8)				.72 (8)		.77 (8)
MEG2*		-.76 (8)				.80 (8)	.79 (8)	.77 (8)
MEG15*		-.71 (8)						
MEG21*		-.74 (8)				.74 (8)	.74 (8)	.71 (8)
MEG25*		-.75 (8)				.76 (8)	.74 (8)	.78 (8)
LC1								.80 (7)
LC2						.80 (7)	.78 (7)	.79 (7)
LC3						.80 (7)	.78 (7)	.80 (7)
LC8								.88 (7)

*The transformation x = log(c) + 1, where c = chemical concentration, was made for each chemical test.

TABLE C-42. HEALTH-RELATED BIOLOGICAL TEST COMBINATIONS SHOWING CORRELATIONS ≥0.50 AND SIGNIFICANCE LEVELS <0.05

ALL SOLID SAMPLES COMBINED, SPEARMAN CORRELATIONS (CORRELATION, NUMBER OF OBSERVATIONS)

Biological tests, health-related	Biological test, health-related							
	RAM 1000	VIABIND	ATP	PROBVI	PROBATP	AMES1	AMES2	RAM
RAM 1000		.90 (9)	.98 (9)	−.97 (5)	−.97 (5)	−.77 (9)		
VIABIND			.88 (9)	−.97 (5)	−.97 (5)	−.70 (9)		
ATP				−.97 (5)	−.97 (5)	−.77 (9)		
PROBVI						.89 (5)		
PROBATP						.89 (5)		
TA98M							.78 (9)	
TA98P							.84 (9)	
TA100M							.72 (9)	.76 (9)
TA1538P							.81 (9)	.74 (9)
AMES2	−.76 (9)	−.68 (9)	−.76 (9)	.92 (5)	.92 (5)	.98 (9)		.80 (9)
RAM	−.72 (9)	−.72 (9)	−.72 (9)	.89 (5)	.89 (5)	.87 (9)	.80 (9)	

APPENDIX D

BATTELLE PATTERN RECOGNITION REPORT

Dr. James Hoyland of Battelle-Columbus Laboratories (BCL) examined an earlier version of this data set using a pattern recognition program specially developed at BCL for chemical data. A few minor changes were made to correct the data set but the authors did not consider them significant in influencing Dr. Hoyland's conclusions. His preliminary report follows.

PRELIMINARY REPORT

on

DATA INTERPRETATION BY PATTERN RECOGNITION

to

ENVIRONMENTAL PROTECTION AGENCY

BATTELLE
Columbus Laboratories

Contract 68-02-2686
Directive 105

INTRODUCTION

This report deals with an initial cursory analysis of biological and chemical data from 51 samples. There are 48 possible biological properties and 150 chemical properties, although most data sets are extremely incomplete. The objective of this preliminary study is to assess the probability that pattern recognition studies may be of value in determining causal relationships between the chemical data and measured biological activity.

DATA SETS

The data sets used for the preliminary analysis were obtained from Ms. Nancy Gaskins of Research Triangle Institute. These data have been stored on disk files at Battelle in such a way that missing items have been flagged. All mathematical analysis of this data is carried out on a PDP-11/34 minicomputer equipped with a floating point processor and located in the investigator's laboratory.

PRELIMINARY STUDIES

The first study carried out was a completeness analysis of the chemical data. This is done by printing a 150 x 51 matrix of 1's or o's. A 1 indicates that a value for that particular item was given, whereas an o indicates the contrary. The print-out of this analysis is included and is labeled "logical Analysis of Chemical Data". Variables 1-74 (spark source elemental analysis) are by far the most complete. In contrast, there is a marked paucity of organic data, which is extremely distressing in that it is expected that the latter will be very important for determining biological acitivty. These data are items 75-100 (MEG 1-MEG 26), 108-115 (LC1 - LC8), and 116-122 (GC7-GC13).

It is of paramount importance in pattern recognition analysis to be able to form a large consistent data set made up of the variable to be classified (predicted) and the implied causal parameters. To this end, a second study was made in which several biological parameters were chosen, the samples for which these variables are known are selected, and a completeness analysis of the chemical parameters for this subset is made. The results of this analysis for the following biological parameters are shown in an accompaning printout:

Parameter Number	Parameter
1	RAM
4	Viability
5	ATP
6	Probit-Viability
7	Probit-ATP
10	Rat-Other
12	Fresh Water Algae
16	96-Hour Fresh Water Fish
18	48-Hour Daphnia
21	96-Hour Salt Water Fish
24	96-Hour Shrimp
25	Rat Weight

A perusal of this analysis is discouraging. Data sets of, at best, marginal size due to lack of biological data are further decimated by holes in the chemical data. This makes accurate assessment of important variables by pattern recognition techniques both statistically suspect and difficult to carry out.

The usual way of assessing the importance of variables is to logically separate the data set into a few discrete classes and then examine the ratio of the inter- to intra- class variance of the causal parameters to decide which are most important for inducing class separation. These ratios, however, are dependent on the number of members in each class and the total number of samples so that in order to generate results which can be interpreted it is mandatory that the same independent variables be known for each sample. It is obvious that this is not true in the present case. Another variable assessment scheme was therefore used which is a measure of the uniqueness of the range of a given independent variable within classes. This is in keeping with the fundamental assumptions of pattern recognition that at least some variables or combination thereof must be within unique ranges within given classes or no separation is possible. The uniqueness varies between o (all classes are spanned by the same range of the independent variable) and 1 (all intra- class ranges are unique and there is no overlap).

In order to carry out uniqueness studies as simply as possible, the completeness analysis results by biological parameter were carefully considered. For each such biological variable, several uniqueness calculations were carried out by selecting a set of chemical parameters all of which are known for several samples, arbitrarily partioning the biological data into two classes (too little data are available to consider more classes than this), computing the uniqueness of the selected chemical parameters, and noting only those which have a uniqueness of at least 0.5.

The computer printout of the results is included. The program is used interactively. The first entry required is the biological variable and a template. The latter term refers to which chemical parameter is utilized to serve as a model for determining which other chemical parameters are also tested. For example, using Bio 1 and Chemical 1 as a template, the computer automatically picks all chemical parameters for which values are known for the first 14 samples listed in the completeness studies by biological parameter. These would be chemical parameters 1-5, 6-10, 12, 14-34, 36-46, 48-57, 59-63, 65-67, 69, 70, 72, and 73. The next entry required is the numerical splitting value. Samples with the biological variable less than this value are placed in Class 1 and those with a biological variable greater than this value are placed in Class 2.

It is extremely difficult to assess the significance of the results of this study due to the very small sample size. We therefore view these results as suggestive rather than definitive in anyway. Further pattern recognition work could be carried out using this study as a basis for choosing chemical variables to consider, but it is felt that such studies will in all probability lead to many false conclusions due to the sparsity of data (i.e., they will not be statistically significant).

Chemical parameter 55 (cobalt concentration) appears to perhaps be related to RAM results (biological variable 1) since it appears ubiquitously for many template values. Parameter 104 (NO_3^-) appears also in all templates capable of extracting it implying some relationship is possible. The small data set obviates attempts to make any further conclusions.

RAM viability (Biological variable 4) is known for 32 of the 51 samples, thereby making it the best variable for study in a statistical sense. Most spark source data is available for 30 of these samples, representing again the best possible chance of producing a statistically sound uniqueness study on these latter parameters. Unfortuantely, no good parameters were found although several partioning schemes were tried. Too little organic data are known to do any meaningful assessment. The study using parameter 76 as a template is considered to be statistically worthless since only two members can logically be placed in Class 1.

Biological variable 5 (RAM-ATP) is known for only 16 samples. Again, cobalt (55) is implied to be related to ATP, as is calcium (62) since these species appear with all templates. It is also tempting to suggest some relationship may exist with 115 (LC8), but this must be confirmed with a much larger data set.

Analysis of the probit data (Biological variables 6 and 7) is not suggestive of any meaningful results. A large number of parameters move in and out of the lists at random as the template is changed implying a lack of sufficient data. The same conclusion is reached for Biological variable 10 (rat-other).

Sulfur (chemical parameter 65) apperas to be related to survival of fresh-water algae (Biological variable 12). All other parameters which might appear at first sight to be important occur randomly depending on template except perhaps for barrium (29) and sodium (70).

Studies on other biological variables (96-hour fresh water fish, 48-hour daphnia, 96-hour salt-water fish, and rat weight) did not lead to any immediate conclusions concerning chemical parameters which might be important for class separation.

PRELIMINARY CONCLUSIONS

A few possibly important chemical parameters based on a uniqueness criterion have been found which may be related to three types of biological activity. Normally, a full pattern recognition analysis would now be carried out to determine the predictive power of these chemical parameters. It is the investigator's opinion, however, that the current data base is too sparse to draw any meaningful conclusions from such studies since it is not possible to mask artifacts which can lead to false deduction concerning the parameters and their values which appear to separate the classes. Further, such studies would not have any degree of statistical significance.

A further problem which must be addressed is the fact that liquid effluents should be studied apart from solids. Different biological uptake methods may apply which can lead to parameter randomization and false conclusions. This was not attempted in this preliminary study since it would further reduce the size of data sets available.

It is recommended that EPA consider the possibility of delaying further work on this project if more data are to be known in the near future. If no new data will be available, two options exist. The first is to continue the current studies even though it is extremely unlikely that any meaningful results will be obtained. The investigator does not recommend this alternative since it would appear to be wasteful of funds which may be used to better purpose elsewhere and from the purely scientific view that generation and publication of such data is distasteful. The second alternative is to terminate this task at this point and recommit the remaining funds to other projects.